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Compilation of 1989 Annual Reports of the Navy ELF Communications System Ecological Monitoring Program

Volume 1 of 3 Volumes:
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This is the eighth compilation of annual reports for the Navy's ELF Communications System Ecological Monitoring Program. The reports document the progress of eight studies performed during 1989 near the Naval Radio Transmitting Facility -- Republic, Michigan. The purpose of the monitoring is to determine whether electromagnetic fields produced by the ELF Communications System will affect resident biota or their ecological relationships.

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FOREWORD

During 1989, the U.S. Department of the Navy continued to conduct a long-term program to monitor for possible effects to resident biota and their ecological relationships from operation of the Navy's Extremely Low Frequency (ELF) Communications System. These studies were funded by the Space and Naval Warfare Systems Command (SPAWAR) through a contract to IIT Research Institute (IITRI). IITRI provided engineering support and overall program management for the ecological studies. Monitoring projects were funded as subcontract agreements between IITRI and university investigators.

The compiled reports document the technical progress and findings of monitoring projects performed near the Naval Radio Transmitting Facility--Republic, Michigan during 1989. As in the past, each report has been reviewed by four or more scientific peers, and investigators have considered and addressed peer critiques prior to providing a final document for this compilation. The reports are presented without further change or editing by SPAWAR or IITRI.

Data collection for studies at the Naval Radio Transmitting Facility--Clam Lake, Wisconsin were completed during 1989, as scheduled. The results and conclusions of studies of bird species and communities are included in this compilation; a final summary report based on data collected over the entire term of the project should be available by the end of 1990. Final summary reports for the other Wisconsin studies (wetland flora and slime molds) are available from the National Technical Information Service (NTIS).

Past compilations, executive summaries, and engineering reports are also available from NTIS. A listing of all documents prepared since the inception of the program in 1982 follows the index of 1989 annual reports.

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ECOLOGICAL MONITORING PROGRAM

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1. Guntenspergen, G.; Keough, J.; Stearns, F.; Wilkum, D. ELF Communications System Ecological Monitoring Program: Wetland Studies--Final Report. IIT Research Institute, Technical Report E06620-2, 1989. 162 pp. plus appendixes.

2. Goodman, E.; Greenebaum, B. ELF Communications System Ecological Monitoring Program: Slime Mold Studies--Final Report. IIT Research Institute, Technical Report E06620-3, 1990. 43 pp. plus appendixes.

Compilations

3. Compilation of 1988 Annual Reports of the Navy ELF Communications System Ecological Monitoring Program. IIT Research Institute, Technical Report E06595-6, 1989. Vol. 1, 572 pp.; Vol. 2, 351 pp.; Vol. 3, 449 pp.

4. Compilation of 1987 Annual Reports of the Navy ELF Communications System Ecological Monitoring Program. IIT Research Institute, Technical Report E06595-2, 1988. Vol. 1, 706 pp.; Vol. 2, 385 pp.; Vol. 3, 491 pp.

5. Compilation of 1986 Annual Reports of the Navy ELF Communications System Ecological Monitoring Program. IIT Research Institute, Technical Report E06549-38, 1987. Vol. 1, 445 pp.; Vol. 2, 343 pp.; Vol. 3, 418 pp.

6. Compilation of 1985 Annual Reports of the Navy ELF Communications System Ecological Monitoring Program. IIT Research Institute, Technical Report E06549-26, 1986. Vol. 1, 472 pp.; Vol. 2, 402 pp.; Vol. 3, 410 pp.

7. Compilation of 1984 Annual Reports of the Navy ELF Communications System Ecological Monitoring Program. IIT Research Institute, Technical Report E06549-17, 1985. Vol. 1, 528 pp.; Vol. 2, 578 pp.

8. Compilation of 1983 Annual Reports of the Navy ELF Communications System Ecological Monitoring Program. IIT Research Institute, Technical Report E06549-8, 1984. Vol. 1, 540 pp.; Vol. 2, 567 pp.

9. Compilation of 1982 Annual Reports of the Navy ELF Communications System Ecological Monitoring Program. IIT Research Institute, Technical Report E06516-5, 1983, 402 pp.

Electromagnetic Engineering

10. Haradem, D. P.; Gauger, J. R.; Zapotosky, J. E. ELF Communications System Ecological Monitoring Program: Electromagnetic Field Measurements and Engineering Support--1988. IIT Research Institute, Technical Report E06595-5, 1989, 69 pp. plus appendixes.

11. Haradem, D. P.; Gauger, J. R.; Zapotosky, J. E. ELF Communications System Ecological Monitoring Program: Electromagnetic Field Measurements and Engineering Support--1987. IIT Research Institute, Technical Report E06595-1, 1988, 54 pp. plus appendixes.

12. Haradem, D. P.; Gauger, J. R.; Zapotosky, J. E. ELF Communications System Ecological Monitoring Program: Electromagnetic Field Measurements and Engineering Support--1986. IIT Research Institute, Technical Report E06549-37, 1987, 52 pp. plus appendixes.

13. Brosh, R. M.; Gauger, J. R.; Zapotosky, J. E. ELF Communications System Ecological Monitoring Program: Electromagnetic Field Measurements and Engineering Support--1985. IIT Research Institute, Technical Report E06549-24, 1986, 48 pp. plus appendixes.

14. Brosh, R. M.; Gauger, J. R.; Zapotosky, J. E. ELF Communications System Ecological Monitoring Program: Measurement of ELF Electromagnetic Fields for Site Selection and Characterization--1984. IIT Research Institute, Technical Report E06549-14, 1985, 37 pp. plus appendixes.

15. Enk, J. O.; Gauger, J. R. ELF Communications System Ecological Monitoring Program: Measurement of ELF Electromagnetic Fields for Site Selection and Characterization--1983. IIT Research Institute, Technical Report E06549-10, 1985, 19 pp. plus appendixes.

Program Summaries

16. Zapotosky, J. E. Extremely Low Frequency (ELF) Communications System Ecological Monitoring Program: Summary of 1988 Progress. IIT Research Institute, Technical Report E06620-1, 1989, 74 pp. plus appendixes.

17. Zapotosky, J. E. Extremely Low Frequency (ELF) Communications System Ecological Monitoring Program: Summary of 1987 Progress. IIT Research Institute, Technical Report E06595-3, 1989, 64 pp. plus appendixes.

18. Zapotosky, J. E. Extremely Low Frequency (ELF) Communications System Ecological Monitoring Program: Summary of 1986 Progress. IIT Research Institute, Technical Report E06549-39, 1987, 63 pp. plus appendixes.

19. Zapotosky, J. E. Extremely Low Frequency (ELF) Communications System Ecological Monitoring Program: Summary of 1985 Progress. IIT Research Institute, Technical Report E06549-27, 1986, 54 pp. plus appendixes.

20. Zapotosky, J. E. Extremely Low Frequency (ELF) Communications System Ecological Monitoring Program: Summary of 1984 Progress. IIT Research Institute, Technical Report E06549-18, 1985, 54 pp. plus appendixes.

21. Zapotosky, J. E.; Abromavage, M. M.; Enk, J. O. Extremely Low Frequency (ELF) Communications System Ecological Monitoring Program: Summary of 1983 Progress. IIT Research Institute, Technical Report E06549-9, 1984, 49 pp. plus appendixes.

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ELF COMMUNICATIONS SYSTEM ECOLOGICAL MONITORING PROGRAM: HERBACEOUS PLANT COVER AND TREE STUDIES

The Michigan Study Site

Tasks 5.13/5.14

ANNUAL REPORT 1989

SUBCONTRACT NUMBER: E06595-88-C-001

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INTRODUCTION

Forest vegetation is the dominant cover type on the ELF Communications Antenna System area. In 1982, Michigan Technological University initiated research at the Michigan antenna site which would determine whether ELF electromagnetic (EM) fields cause changes in forest productivity and health. Work elements were initiated at control, antenna and ground treatment plots to establish a baseline of data that could be used to compare various aspects of these communities both before and after the antenna becomes activated. This approach is the the most rigorous for evaluating possible effects of ELF fields on forest ecosystems.

Our overall project objective remains, to assess the impact of ELF fields on forest productivity and health.

To accomplish this, more specific objectives of the work elements are to determine the impacts of ELF electromagnetic fields on:

1) growth rates of established stands, individual hardwood trees and red pine seedlings,
2) timing of selected phenological events of trees, herbs and mycorrhizal fungi,
3) numbers and kinds of indigenous mycorrhizae on red pine seedlings,
4) nutrient levels of hardwoods and red pine,
5) foliage production in hardwoods,
6) insect and disease status of hardwood and pine stands.

Ultimately, the question of whether ELF electromagnetic fields measurably impact forest communities will be answered by testing various hypotheses (Table 1) based on the results of long-term studies.

PROJECT DESIGN

Overview of Experimental Design

Much of the effort in this study has been dedicated to developing a statistically rigorous design to separate what may be very subtle ELF field effects on response variables from the existing natural variability caused by soil, stand and climatic factors (Mroz etal. 1985). Consequently, to test our hypotheses it has been imperative to directly measure both plant growth and important regulators of the growth process such as tree, stand, and site factors in addition to ELF fields at the sites (Table 2). These measurements and associated analyses are discussed more fully in the various work element sections of this report. Work elements group similar measurements and analyses but are interrelated, with data from several elements often used to test a single hypothesis (Table 2).

Table 1. Critical hypotheses that will be tested to fulfill the objectives of the ELF environmental monitoring program Upland Flora project.

I. There is no difference in the magnitude or the pattern of seasonal diameter growth of hardwoods before and after the ELF antenna becomes activated.

II. There is no difference in the magnitude of diameter growth of red pine seedlings before and after the ELF antenna becomes activated.

III. There is no difference in the magnitude or rate of height growth of red pine seedlings before and after the ELF antenna becomes activated.

IV. There is no difference in the rate of growth and phenological development of the herb, *Trientalis borealis* L., before and after the ELF antenna becomes activated.

V. There is no difference in the number of different types of mycorrhizal root tips on red pine seedlings before and after the antenna becomes activated.

VI. There is no difference in the total weight and nutrient concentrations of tree litter before and after the ELf antenna becomes activated.

VII. There is no difference in the foliar nutrient concentrations of northern rd oak trees or red pine seedlings before and after the ELF antenna becomes activated.

VIII. There is no difference in the rate of development of *Armillaria* root disease on red pine seedlings before and after the ELF antenna becomes activated.

Table 2. Measurements needed to test the critical hypotheses of the ELF environmental monitoring program Upland Flora project, the objective it is related to, and the work elements addressing the necessary measurements and analyses.

Hypothesis Number	Related Objectives	Measurements	Work Elements
I	1,2	*Weekly dendrometer band readings** climatic variables, soil nutrients, tree and stand characteristics.	1,2,3
II	1	*Annual diameter growth*, terminal bud size, plant moisture stress, microsite climatic variables, number of mycorrhizae.	1,2,3,5
III	1,2	*Weekly height growth, annual height growth*, terminal bud size, plant moisture stress, number of mycorrhizae, ambient measures.	1,2,3,5
IV	2	Periodic measures of plant dimensional variables including *leaf size* and phenological stages of *flowering, fruiting,* etc., climatic variables.	1,3
V	3	*Monthly counts of mycorrhizal root tips by type,* climatic variables, tree variables.	1,5
VI	5	*Periodic collections of litter, nutrient analyses,* climatical variables.	1,6
VII	4	*Periodic collections of foliage, nutrient analyses*, climatic variables.	1,6
VIII	6	*Monthly inventory of red pine mortality caused by Armillaria root disease,* soil texture, bulk density and rock content; hardwood stump characteristics and density.	2

*Italicized print designates response variables; others listed are covariates.

The experimental design integrates direct measures with site variables and electromagnetic field exposure and is a common thread through nearly all studies due to the field design. An understanding of this experimental design is essential because of the similarity in analyses for hypothesis testing and the complexity of the overall project. The rationale and progress for measurements in each work element of this study are unique and will be presented separately.

Field Design And Electromagnetic Exposure

At the outset of the project, it was known that the electromagnetic fields associated with the ELF system would be different at the antenna and ground locations (Anonymous, 1977). Measurements of 76 hz electric field intensities have been made at the antenna, ground, nd control sites since 1986 when antenna testing began (Haradem etal. 1988). Backgound 60 Hz field levels were measured at all sites in 1985. Three types of electromagnetic (EM) fields are measured for each frequency: magnetic (mG), longitudinal (mV/m), and transverse (V/m). A short description of these follows as summarized from Haradem etal.(1987).

The magnetic field is generated by the antenna and is unchanged at the air/earth boundary. It is expected to diminish with increasing distance from the antenna (being negatively correlated with the inverse of distance) but should remain relatively stable over the length of the antenna. The longitudinal field is in the ground and is parallel, but in the opposite direction to the current in the antenna. Additional longitudinal fields are generated by the ground terminal currents. The longitudinal field is affected by soil conductivity and moisture, as well as other properties such as amount of rocks and roots. The longitudinal field will vary along the length of the antenna and with distance from the antenna. The transverse field is in the air and also diminishes with the inverse of distance from the antenna. The transverse field can be affected by vegetation and other conductive objects so it can also vary considerably over short distances and along the antenna. As a consequence of the differences in fields associated with antenna and ground sites, forest vegetation at each site could be differentially affected by both above and below ground fields. Therefore, the general approach of the study required plots to be located along a portion of the antenna, at the ground terminal, and at a control location some distance from the antenna.

The experimental design is best described as a split plot in space and time. Each site (control, antenna, and ground) is subjected to a certain level of ELF field exposure and is subdivided into two subunits (hardwood stands and red pine (Pinus resinosa Ait.) plantations) (Figure 1). These stand types comprise the treatments for

the second level of the design. Each stand type is replicated three times on a site (where sites represent different levels of ELF field exposure) to control variation in non treatment factors that may affect growth or health such as soil, stand conditions and background and treatment electromagnetic field levels. The time factor in the design is the number of years that an experiment is conducted for baseline to treatment comparisons, or the number of sampling periods in one season for year-to-year comparisons. It is necessary to account for time in the experimental design since successive measurements are made on the same plots and individual trees over a long period of time without rerandomization. A combined analysis involving a split plot design is made to determine both the average treatment response (site difference) over all years and consistency of such responses from year to year (Steel and Torrie 1980).

Each site follows this design with one exception. There is no hardwood stand at the ground site because required buffer strips would have resulted in the stands being too distant from the ground for sufficient exposure to ELF fields. Depending on the variable of interest, the stand type treatment factor may or may not be pertinent. In those cases where measurements are made on only one stand type, it becomes irrelevant and falls out of the analysis. All other factors remain unchanged.

Figure 1. Diagram of the control plot as an example of the experimental design units.

Control Site

(Whole Unit)

Plot 1	Plot 2	Plot 3	(Subunit) Hardwood Stand

sham right of way

Plot 1	Plot 2	Plot 3	(Subunit) Red Pine Plantation

Analysis of Covariance

Our experimental design directly controls error in the field to increase precision. Indirect or statistical control can also increase precision and remove potential sources of bias through the use of covariate analysis. This involves the use of covariates which are related to the variable of interest. Covariate analysis removes the effects of an environmental source of variation that would otherwise contribute to the experimental error. The covariate need not be a direct causal agent of the variate, but merely reflect some characteristic of the environment which also influences the variate (Cochran 1957). Thus, determining covariates which are both biologically meaningful as well as independent of treatment effects continues to be one of the most important steps in our analysis.

Covariates under examination vary for a given variable of interest (Table 2). Most analyses use ambient climatic variables, such as air temperature, soil temperature, soil moisture, precipitation, and relative humidity, as well as variables computed from these data, such as air temperature degree days, soil temperature degree days and cumulative precipitation. Depending on the variable of interest, microsite factors will also be considered. Other factors considered are more specific to the variable; for example, covariates in the analysis of red pine height growth would include bud size, seedling diameter, and total height of the seedling at the beginning of the study in addition to ambient factors. Analyses are being conducted to determine which of these are both statistically significant as well as biological meaningful without violating the necessary assumptions of treatment independence required for the analysis of covariance (Cochran 1957). The most general and encompassing ANOVA table for the project is shown in Table 3. More detailed ANOVA tables can be found in each work element section of this report

Testing for ELF Field Effects

This report covers the sixth year (1984-1989) of actual data collection and evaluation for most elements although analyses requiring EM field intensities only include the fifth year of data (1984-1988). Only five years of weather related measurements are complete (1985 through 1989). Measurements of 60 Hz and 76 Hz field intensities are available for 1986 through 1988 (1989 measurements will be included in next years report). Background fields are also available for 1985. Observations of field intensities are made once a year at the corners of the measurement plots and some other locations as described by Haradem *etal.* (1989). The field intensities are affected by vegetative and soil factors and do not strictly behave according to EM theory

Table 3. Generalized analysis of variance table for the trees and herbaceious plant cover study.

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	F-Ratio
Covariates	# Coveriates			
Plot	2	SS_P	MS_P	$MS_P/MS_{E(S)}$
Site	2	SS_S	MS_S	$MS_S/MS_{E(S)}$
Error (S)	4-# Covariates	$SS_{E(S)}$	$MS_{E(S)}$	
Stand Type	1	SS_T	MS_T	$MS_T/MS_{E(ST)}$
Site x Stand Type	2	SS_{ST}	MS_{ST}	$MS_{ST}/MS_{E(ST)}$
Error (ST)	6	$SS_{E(ST)}$	$MS_{E(ST)}$	
Years	#yrs-1	SS_Y	MS_Y	$MS_Y/MS_{E(SY)}$
Site x Years	(2) (#yrs-1)	SS_{SY}	MS_{SY}	$MS_{SY}/MS_{E(SY)}$
Error (SY)	(2)(2)(#yrs-1)	$SS_{E(SY)}$	$MS_{E(SY)}$	
Stand Type x Year	(1)(#yrs-1)	SS_{TY}	MS_{TY}	$MS_{TY}/MS_{E(TY)}$
Site x Stand Type x Year	(2)(1)(#yrs-1)	SS_{STY}	MS_{STY}	$MS_{STY}/MS_{E(STY)}$
Error (STY)	(2)(3)(1)(#yrs-1)	$SS_{E(STY)}$	$MS_{E(STY)}$	

and treatment levels have not been uniform over time because of the various testing phases prior to antenna operation. To control variability in the actual treatment exposure and to improve our ability to detect what may be an extremely subtle response, we are attempting to interpolate field exposures for individual measurement points on the plots. This is true for individual tree locations in the productivity studies, the litter trap locations in the litter studies, and other such locations in other elements. After year-long discussions with IITRI scientists, we have come up with a first cut at the approach used to account for EM field variability across the sites and over time. This is described below. The form of the equation used for interpolation in 1988 will be used in subsequent years to obtain exposure data for locations within the plots.

Given the physical expectations for field strength behavior along and away from the antenna described above, a stepwise regression procedure was used to develop equations for interpolating field exposures from the plot corners to interior locations:

$$\text{Field Strength} = a_0 + a_1 X + a_2 / X + a_3 Y$$

where field strength is in mG, V/m, or mV/m depending on the field of interest, X is the perpendicular distance from the antenna, and Y is the distance along the antenna. The coordinate systems for each site are given in Appendix A. During the regression procedure, indicator variables were used to examine differences between 1986, 1987, and 1988 in each field on each site. The resulting equation systems for calculating exposure levels within the plots are given in Appendix A.

From the interpolation equations, an average field exposure level is obtained for locations within the study plots. Records of the number of on-off cycles and hours of antenna operation are available for 1986, 1987, and 1988 (Haradem *et al.* 1989). Average field exposure, number of on-off cycles, hours of exposure, and interactions of these terms, will be used in the various elements to estimate EM field exposure levels and to investigate the effects of these fields on biological activities.

Since the antenna was activated for low level testing throughout the growing seasons of 1987 and 1988 and full power operation in late 1989, hypothesis testing will examine differences in response variables between these and previous years, and differences between control, antenna and ground sites in 1987 through 1989 (Testing varies by element with those elements dependent on soil or foliar chemical analyses generally dealing only with data through 1988 at this time. This is due to the lag time in laboratory analyses.)

The most extensive comparisons will be the for yearly and site within year differences. For all hypotheses, ambient and other variables (Table 2.) will be used to

explain site and year differences. If there are no differences between 1987 and 1988 and previous years, no differences between sites in 1987 or 1988, and/or differences between sites is stable before and during 1987 and 1988, we can then infer that the antenna operation had no detectable effects on the response variable. For those elements where analysis of covariance is used, we will test to insure that covariates are statistically independent and then see if fields explain site and year differences for a particular response variable. If site and year differences are apparent in the modelling effort, correlation will be used to determine whether residuals from these analyses are related to ELF fields.

Detection Limits

Where detection limits for response variables are described in an elements they equal the amount of change in the response variable for which there is a 50 percent chance of detecting (using a significance level of 0.05 unless otherwise noted) given the statistical design and sample size in this study. These are calculated as follows (Zar, 1974):

$$\text{Detection Limit} = (SE) * q_{.05,df,p=2}$$

where SE is the standard error for the response variable, $q_{.05,df,p=2}$ is the critical value of the Student-Newman-Keuls multiple range test using a significance level of 0.05 unless otherwise noted and p=2. There is a greater than 50 percent chance that a change in the response variable due to ELF fields which is greater than the detection limit will be detected by the study design; a change less than the detection limit has less than a 50 percent chance of being detected. In most cases, if detection limits did not increase or decrease more than 20% over last year (Mroz et al. 1988), they are not presented.

Work Elements

As stated earlier, the various work elements of this project were established to group similar tasks and analyses. Although data from several work elements are often used to test a single hypothesis, we retain the work element format in this report to allow the reader to easily refer to details presented in past annual reports. Each of the following sections presents a synopsis of the rationale for study, measures and analyses, and progress.

Element 1: AMBIENT MONITORING

The growth and development of a forest community or an individual in the community is directly related to the environmental factors (natural and anthropogenic) which influence the physical space that the community or individual occupies. Any study which attempts to relate the development of a population to any one of these factors must also determine and screen out the effects of other independent factors. Thus, variability in plant growth, development, or phenological events within the influence of the ELF antenna system must first be related to microclimatic and other ambient variables before the effect of a single and potentially subtle factor, such as the electromagnetic fields of the ELF antenna, can be quantified (National Research Council, 1977).

Given the overall importance of ambient factors to the Upland Flora Project, the objectives of this monitoring work element are to:

1. evaluate the natural ambient differences between the control site and the test sites.

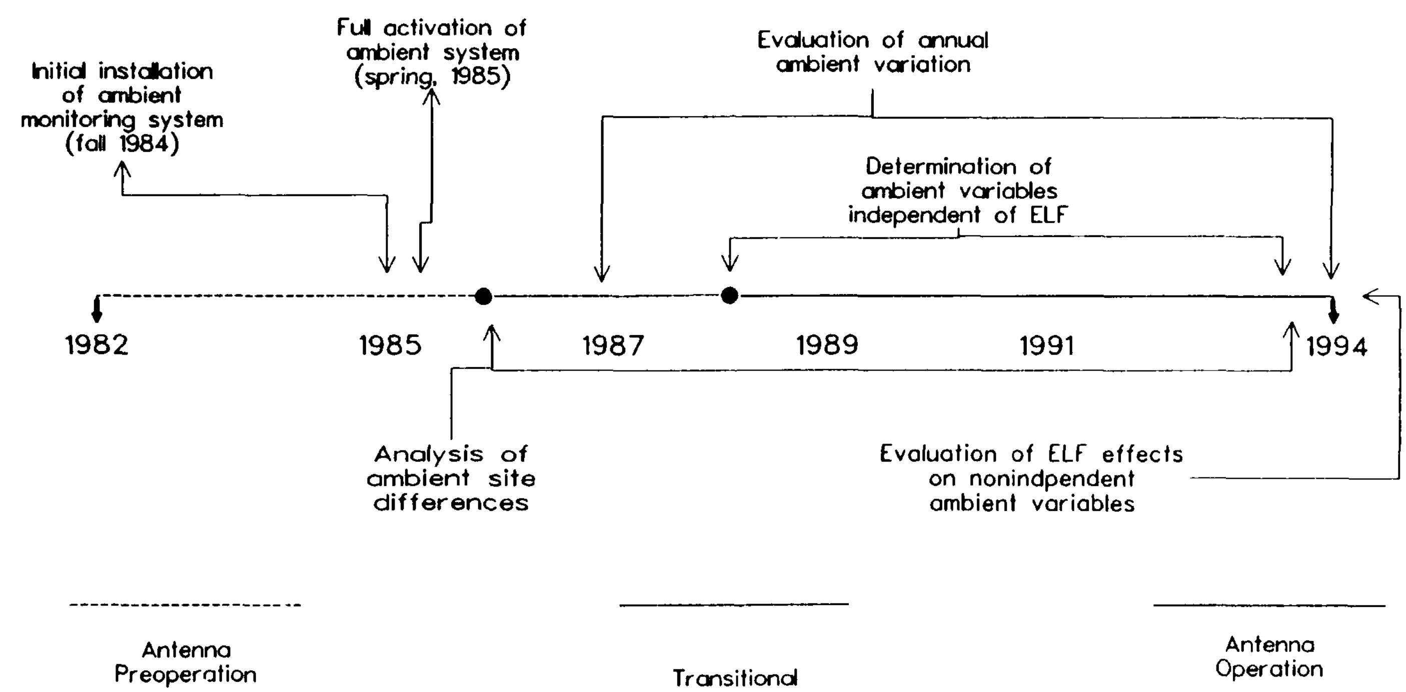
2. evaluate the natural annual ambient changes of a site over time to determine differences between pre-operational and operational time periods.

3. select ambient variables which are independent of ELF system effects which can then be included in a database which can be used to (1) build models to predict community growth and development and (2) supply ambient variables as covariates for community growth and development analysis.

4. evaluate possible ELF system effects on non-independent ambient variables detected through the screening process in objective 3.

Accomplishing these objectives will not only document ambient differences among sites and annual changes in these conditions but also quantify ambient variables which are employed in the growth and development modeling in the various study elements. An adequate database of ambient measurements will insure a proper analysis of climatic and soil relationships to other study components as discussed in the design section dealing with covariate analysis. Accomplishment of the last objective will give direct measurement of any ELF system influences on such factors as solar radiation in the understory or soil nutrient status that may be affected by overstory biomass. The initiation and schedule of each phase of the objectives are presented in Figure 1.1.

Figure 1.1 Schedule and Initiation of ambient monitoring objectives.



Work on the Upland Flora Project during the past five years has indicated that soil and possibly precipitation chemistry is important to the project's growth modeling efforts. Thus an increased emphasis has been placed on the collection and analysis of these variables. The ambient monitoring element is separated into two sections: climatic monitoring and nutrient monitoring.

Climatic Monitoring

Sampling and Data Collection

System Configuration

The climatic variables being measured in the study are air temperature (30cm and 2m above the ground), soil temperature and soil moisture at depths of 5 and 10 cm, global solar radiation, relative humidity, photosynthetically active radiation (PAR), and precipitation. The configuration and placement of the sensors at the study sites have been presented in Appendix B (Table 1) of the 1985 Herbaceous Plant Growth and Tree Studies Project annual report.

Because of the location of individual sensors, air temperature (2 meters above the ground) in the plantation, precipitation, relative humidity, and global solar radiation are considered to be independent of possible ecological changes caused by ELF electromagnetic fields. Air temperature at the hardwood stands, soil temperature, soil moisture, air temperature (30 cm above the ground), and PAR (30 cm above the ground) may be sensitive to ecological changes related to stand characteristics and thus by possible effects of ELF electromagnetic fields.

Air temperature, soil temperature, PAR, and relative humidity are measured every 30 minutes by a Handar, Inc. ambient monitoring platform. Global solar radiation is measured every 60 minutes, soil moisture is sampled every 3 hours, and precipitation monitored continuously. A microprocessor on board the ambient system calculates three hour averages or totals for the appropriate climatic variables. These averages and totals as well as the soil moisture and global solar radiation measurements are transmitted to the GOES East satellite every three hours and relayed to Camp Springs, Virginia. The data are transferred from Camp Springs to an IBM PC at MTU nightly.

Soil moisture subsampling procedures are performed at each site in order to more accurately measure soil moisture over the entire area of each plot. Twenty cores are randomly taken from each plot at each site once a month. Moisture content for each depth (5 cm and 10 cm) is determined gravimetrically from a composite of the cores

from a plot. These moisture contents are considered to represent the average moisture content for a given plot for the day of core sampling.

Differences between the soil moisture calculated from the cores and readings from the soil moisture sensors for a given plot and day of core collection are used as an adjustment for the soil moisture readings for each plot over a monthly time interval. To eliminate any abrupt changes in soil moisture between consecutive months which would be attributed to the monthly adjustment, the weighting equation (1.1) is used to determine the actual monthly soil moisture sensor adjustments. The equation's adjustments for a given month are weighted more heavily to the month of adjustment.

Equation 1.1 Monthly adjustment for a specific plot

$$\frac{(CSM_{(M-1)}-PSM_{(M-1)})+2*(CSM_{(M)}-PSM_{(M)})+(CSM_{(M+1)}-PSM_{(M+1)})}{4}$$

CSM = Core Soil Moisture from the plot

M = Month of Adjustment

M+1 = Following Month

PSM = Probe Soil Moisture from the plot

M-1 = Previous Month

As stated in the 1986 Herbaceous Plant Cover and Tree Studies Annual Report, 1985 soil moisture measurements could not be used in any analyses. Thus the 1989 measurements were only the fourth full year of soil moisture measurement.

System Maintenance and Performance

The performance of the climatic monitoring system in 1988 was enhanced by the installation of lightning protection equipment at the sites through a cooperative effort between MTU and IITRI. Performance of the system since the installation of this equipment has improved dramatically. Downtime of the systems have been virtually eliminated by these improvements.

Data Management

Daily averages or totals, maximums, and minimums are computed for each sensor using all 3 hour measurements (eight/day) transmitted by the platforms. If less than six transmissions are received in a day for an air temperature, relative humidity, or solar radiation sensor daily statistics for that sensor are not calculated. Due to small diurnal variability in soil temperature and soil moisture the transmission limits for calculation of daily statistics for these sensors are four and two transmissions

respectively. Weekly and monthly averages or totals are then computed from these summaries.

Weekly or seven day summaries comprise the basic climatic unit used by the tree productivity study (element 2). One summary generated from the climatic information is adjusted to correspond to the weekly measurements of tree diameter or height. For example if red pine height growth and hardwood tree diameter growth was determined for the seven days from May 9 through May 15, weekly ambient summaries are also calculated for these same seven days. This insures a consistent relationship between tree productivity measurements and climatic measurement summaries. Weekly averages are considered missing and not calculated if less than four daily averages are computed from a sensor for a given seven day period. Daily climatic information is summarized in the same manner to correspond to sampling periods in each of the other project elements.

Monthly averages and totals are the basic unit used for site and year comparisons in this study element. Weekly averages and totals corresponding to seven day periods in a month are calculated from the daily climatic averages and totals (Table 1.1). These weeks are used as repeated replicate samples for each plot during each month during the growing season (refer to analysis section).

Table 1.1. Example of weekly units.

Date	Week
May 1-7	1
May 8-14	2
May 15-21	3
May 22-30	4

Missing Data Replacement

As the result of platform and sensor downtime in the past five years, daily climatic averages or totals are estimated for days in which specific ambient observations are missing. Four hierarchical criteria and methods are used to replace the missing data. The criteria are:

1) Daily averages missing from one or two plots from a stand type of an individual site are estimated using an average of the daily summaries from the functional plots on the same stand type and site.

2) Missing daily plot averages from adjacent sites (ground and antenna) are replaced by the stand type averages from the plantation on the adjacent site if 1) there are no significant differences between the two

sites 2) there are no significant differences among plots within sites for the variable of interest. Only air temperature and precipitation have met these criteria on the ground and antenna site in the past four years.

3) Missing daily plot averages from the ground or antenna site not estimated by the methods outlined in criteria 2 are predicted using regression equations. These equations are fitted using observed data from the sensor, plot, and site combination with the missing data as the dependent variable and the observed average daily plantation observation from the other adjacent site as the independent variable.

4) Missing plot daily average air temperatures, relative humidity, and total daily precipitation at the control site are estimated from regression equations fitted to individual observed plot averages or totals and daily observations at the Crystal Falls C#200601 weather station. This weather station is located within 9 km of the control site and is operated by the Michigan Department of Natural Resources in Crystal Falls. Missing average daily soil temperatures are estimated using regression equations fitted to stand type daily averages of air temperature at the site.

Using these techniques 95% of the missing daily averages or totals can usually be replaced. Regression equations used in the data replacement along with the related regression statistics for 1985-88 have been presented in previous Herbaceous Plant Cover and Tree Studies annual reports. The 1989 equations are presented in Appendix B (Table 1-3) of this report. Improved performance of the ambient system in 1989 eliminated any need to use criteria 4 for missing data replacement. Criteria 3 was only used to estimate between 3 and 7 days of ground and antenna site information during system startup in early April.

Estimates of climatic measurements obtained from criteria 1-4 are used throughout the project. Coefficients of determination as well as confidence intervals for the equations are well within acceptable limits. It is felt that the missing data replacement methods give unbiased and accurate estimates of climatic measurements and thus the variables are used in the statistical analyses in the various elements.

Data Analysis

Comparisons of site and time differences of the ambient variables generally follow a split-plot in space and time experimental design (Table 1.2). Since plot locations at one site are not related to plot locations at another site, plots are nested within sites. This nesting gives a more sensitive test of main factor effects.

The design through partitioning of variability into a number of factors (site, year, stand type etc.) and associated interactions allow a number of hypotheses to be tested. For example the site factor allows testing differences in climate between sites and year factors can quantify annual changes in climate. To determine if ELF fields are affecting ambient variables at the test sites site by year, site by stand type, and site by stand type by year interactions are used to determine if the relationship of a given ambient variable changes between the stand types or the control and test sites over time. These interaction terms can be used to quantify ELF field effects on climate by relating any temporal changes in climate to antenna preoperational and postoperational phases.

As mentioned previously weekly summaries are the basic unit used for statistical analysis in the element. We consider these weeks as a repeated measure on a given climatic variable. Repeated measures are multiple observations on a specific experimental unit or (in the case of climatic measurements) a specific three dimensional area. Since the observations are made on the same unit they are not independent of each other. Therefore weeks are nested in plots in the design (Table 1.2).

Comparison of ambient variables among sites, years, months, etc. were made using analysis of variance tests. Differences between specific months, years, sites, etc. were made using the Student-Newmen-Keuls (SNK) multiple range test if tests with analysis of variance indicated significant differences for the appropriate factor. Detection limits for each variable were also calculated using this multiple range test. All factors were tested at the 0.05 probability level for the ANOVA and SNK tests.

Analysis of ambient variables, which are only measured on a site level, year level, or on only one stand type, involved only a portion of the experimental design. Analysis of precipitation amounts involved site and year factors only because only one sensor is located at each of the plantations. Since the ground site does not have a hardwood stand type associated with it, analyses were performed for the control vs ground site and the control vs antenna site separately with stand type dropped from the analysis for the control vs ground tests.

Table 1.2. General analysis of variance of Element 1.

Source of Variation	Sum of Squares	Mean Square	F-Ratio
SI	SS(S)	MS(S)	MS(S)/MS(E_1)
PL w SI (Error 1)	SS(E_1)	MS(E_1)	MS(E_1)/MS(E_2)
WK w PL w SI (Error 2)	SS(E_2)	MS(E_2)	
YR	SS(Y)	MS(Y)	MS(Y)/MS(E_3)
YR x SI	SS(YS)	MS(YS)	MS(YS)/MS(E_3)
YR x PLwSI (Error 3)	SS(E_3)	MS(E_3)	MS(E_3)/MS(E_4)
YR x WKwPLwSI (Error 4)	SS(E_4)	MS(E_4)	
ST	SS(T)	MS(T)	MS(T)/MS(E_5)
ST x SI	SS(TS)	MS(ST)	MS(ST)/MS(E_5)
ST x PLwSI (Error 5)	SS(E_5)	MS(E_5)	MS(E_5)/MS(E_6)
ST x WKwPLwSI (Error 6)	SS(E_6)	MS(E_6)	
MO	SS(M)	MS(M)	MS(M)/MS(E_7)
MO x SI	SS(MS)	MS(MS)	MS(M_5)/MS(E_7)
MO x PLwSI (Error 7)	SS(E_7)	MS(E_7)	MS(E_7)/MS(E_8)
MO x WKwPLwSI (Error 8)	SS(E_8)	MS(E_8)	
YR x MO	SS(YM)	MS(YM)	MS(YM)/MS(E_9)
YR x MO x SI	SS(YMS)	MS(YMS)	MS(YMS)/MS(E_9)
YR x MO x PLwSI (Error 9)	SS(E_9)	MS(E_9)	MS(E_9)/MS(E_{10})
YR x MO x WKwPLwSI(Error 10)	SS(E_{10})	MS(E_{10})	
YR x ST	SS(YT)	MS(YT)	MS(YT)/MS(E_{11})
YR x ST x SI	SS(YTS)	MS(YTS)	MS(YTS)/MS(E_{11})
YR x ST x SI (Error 11)	SS(E_{11})	MS(E_{11})	MS(E_{11})/MS(E_{12})
YR x ST x SI x WKwPLwSI(Error 12)	SS(E_{12})		
ST x MO	SS(TM)	MS(TM)	MS(TM)/MS(E_{13})
ST x MO x SI	SS(TMS)	MS(TMS)	MS(TMS)/MS(E_{13})
ST x MO x PLwSI (Error 13)	SS(E_{13})	MS(E_{13})	MS(E_{13})/MS(E_{14})
ST x MO x WKwPLwSI (Error 14)	SS(E_{14})	MS(E_{14})	
YR x ST x MO x SI	SS(YTMS)	MS(YTMS)	MS(YTMS)/MS(E_{15})
YR x ST x MO x PLwSI (Error 15)	SS(E_{15})	MS(E_{15})	MS(E_{15})/MS(E_{16})
YR x ST x MO x WKwPLwSI (Error 16)		SS(E_{16})	MS(E_{16})

Site = SI, S Within=w
Stand Type = ST, T By=x
Year = YR, Y
Month = MO, M
Plot = PL

Progress

This year concludes the fifth full year of data collection by the ambient monitoring system and the third year of low level operation of the ELF antenna. Thus comparisons of sites, years, and site by year interactions are presented and related to possible detection of ELF effects on climatic variables. In previous year's report (Mroz et al. 1988) detection limits were reported for each variable and site comparison. The detection limits associated with these tests were again calculated using this years data. However, the detection limits for a given variable and site comparison will not be presented in this year's report unless they increase or decrease greater than 20% from the detection limits reported in the 1988 report.

In this years report a new emphasis has been placed on determining if the ambient variables are related to the electromagnetic fields which have been measured at the sites during 1985-1988. The objective of this effort is to determine if ambient and climatic factors are correlated to the field exposure at the sites. Significant correlations between these fields and the ambient variables would suggest that either a mechanistic or coincidental relationship exists between the measured ambient variables and ELF antenna operation. Regardless of the actual cause for such a relationship it is important to determine which variables are independent and which variables are confounded with the ELF antenna operation. Variables that are related to ELF fields do not meet the assumptions of independence that is necessary for inclusions as covariates in the statistical designs.

Relationships between ambient measurements and the ELF fields were determined using Pearson Product Moment Correlation Coefficients. Ambient measurements used for the correlations were either growing season averages or totals for each plot and site for each of the years 1985-1988. Average field exposures for each plot were determined by integrating the equations for each field (Appendix A) over the area of the plot. The electromagnetic measurements chosen for the correlations were the 76 hz magnetic flux, 76 hz transverse electric field, and 76 hz longitudinal electric field during the EW leg operation.

Air Temperature (2m above the ground)

Air temperature has a substantial influence on plant physiological processes such as photosynthesis, cell division, and elongation, chlorophyll synthesis, and enzymatic activity (Kramer and Kozlowski 1979). For any individual species given a specific period during the growing season, optimal net photosynthesis is associated with a specific range of temperatures (Waring and Schlesinger 1985). Thus differences in air temperature between the control and test sites or among

study years could have significant effects on vegetation growth and development.

Site Comparisons: As shown in Figures 1.2-1.3 air temperature at the control site is consistently warmer than at the test sites regardless of the stand type compared. Average temperature during the growing season over the five year study period was 0.8°C and 1.0°C warmer at the control site plantation than at the antenna and ground plantations respectively (Table 1.3). Average temperature at the control hardwood stand was 0.8°C warmer than at the antenna hardwood stand. ANOVA tests showed significant differences between the control and ground sites ($p=0.010$) as well as the control and antenna sites ($p=0.001$).

Annual Comparisons: Air temperatures in 1987 and 1988 were warmer than in all other years for all sites and stand types (Table 1.3). ANOVA tests show significant differences among years ($p<0.001$) for both the control vs antenna and control vs ground comparisons. Multiple range tests ($p=0.05$) rank annual air temperature for both comparisons as follows: 1988=1987>1989=1986>1985.

Site by Year Comparisons: Again this year ANOVA tests showed site by year interactions were significant for the control vs ground site ($p<.001$) but not the control vs. antenna site ($p=0.504$) comparison. Differences in average air temperature during the growing season between the control and ground site was 0.5°C in 1985 and increased to 1.5°C in 1988 and 1.4°C in 1989 (Table 1.3). Air temperatures at the control plantation have also increased relative to air temperature at the antenna plantation over this period of time (Table 1.3). However, differences in air temperature between the hardwood stands at the control and antenna have remained stable. Although during the past five years average air temperatures at the control plantation have increased 0.7°C compared to the average air temperature at the antenna plantation while differences in average air temperatures at the control and antenna hardwoods have remained stable, site by year by stand type interactions were not significant ($p=0.217$) in this years analysis.

The stand type by year interaction term was also significant ($p=0.005$) for the control vs antenna comparison. This indicates that changes in air temperature of the two stand types over time were not constant. Table 1.4 shows that no significant differences exist for the average temperatures of two stand types in 1985 to 1987. However, beginning in 1988 temperature differences between the stand

AVERAGE MONTHLY AIR TEMPERATURES
(1985-1989)

Figure 1.2

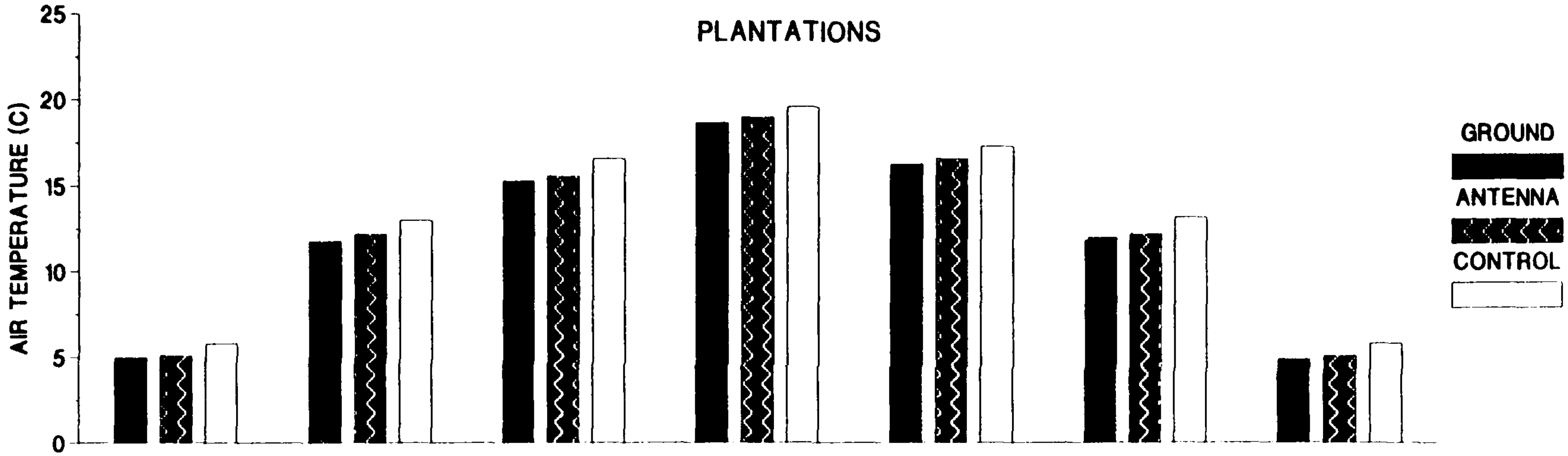


Figure 1.3

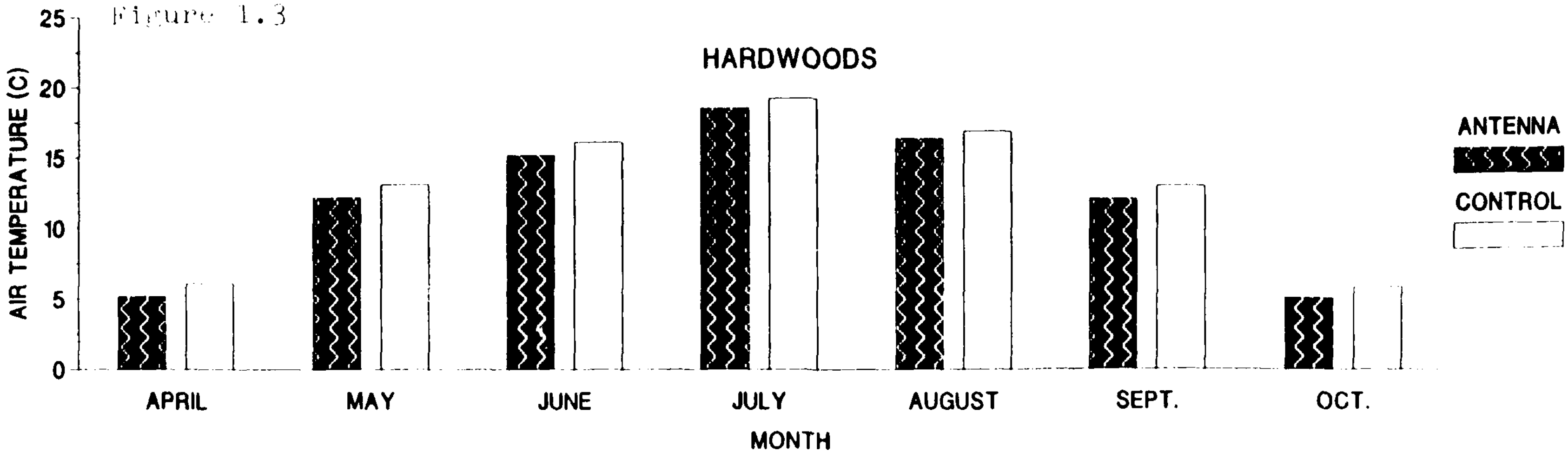


Table 1.3 Comparison of mean air temperature (°C 2 m above ground) during the 1985-89 growing seasons (April-Oct).

	Ground	Antenna	Control	Control-Ground	Control-Antenna
			Plantation		
1985	11.4	11.5	11.9	0.5	0.4
1986	11.9	12.1	12.7	0.8	0.6
1987	12.7	12.9	13.6	0.9	0.7
1988	12.3	12.9	13.8	1.5	0.9
1989	11.8	12.1	13.2	1.4	1.1
Ave.	12.0	12.3	13.0	1.0	0.7
			Hardwoods		
1985		11.4	12.3		0.9
1986		12.0	12.9		0.9
1987		12.7	13.5		0.8
1988		12.5	13.3		0.8
1989		11.8	12.5		0.7
Ave.		12.1	12.9		0.8

Site Comparison

Control[1]	Ground
13.0 a	12.0 b
Control	**Antenna**
13.0 a	12.2 b

Annual Comparison

	Control & Ground	Control & Antenna
1985	11.7 c	11.8 c
1986	12.3 b	12.4 b
1987	13.1 a	13.2 a
1988	13.1 a	13.1 a
1989	12.5 b	12.4 b

[1/] Site or year comparisons with the same letters for a specific site combination are not significantly different ($p=0.05$)

types were significant and average air temperatures in the plantations were consistently warmer than air temperatures in the hardwood stands. Since site by year by stand type interactions are not significant, it appears that relative to the hardwood stands, air temperature in the plantations at the two sites have increased at a similar rates.

Table 1.4. Comparison of average air temperatures from control and antenna plantations to average air temperatures from the control and antenna hardwood stands. during the study period.

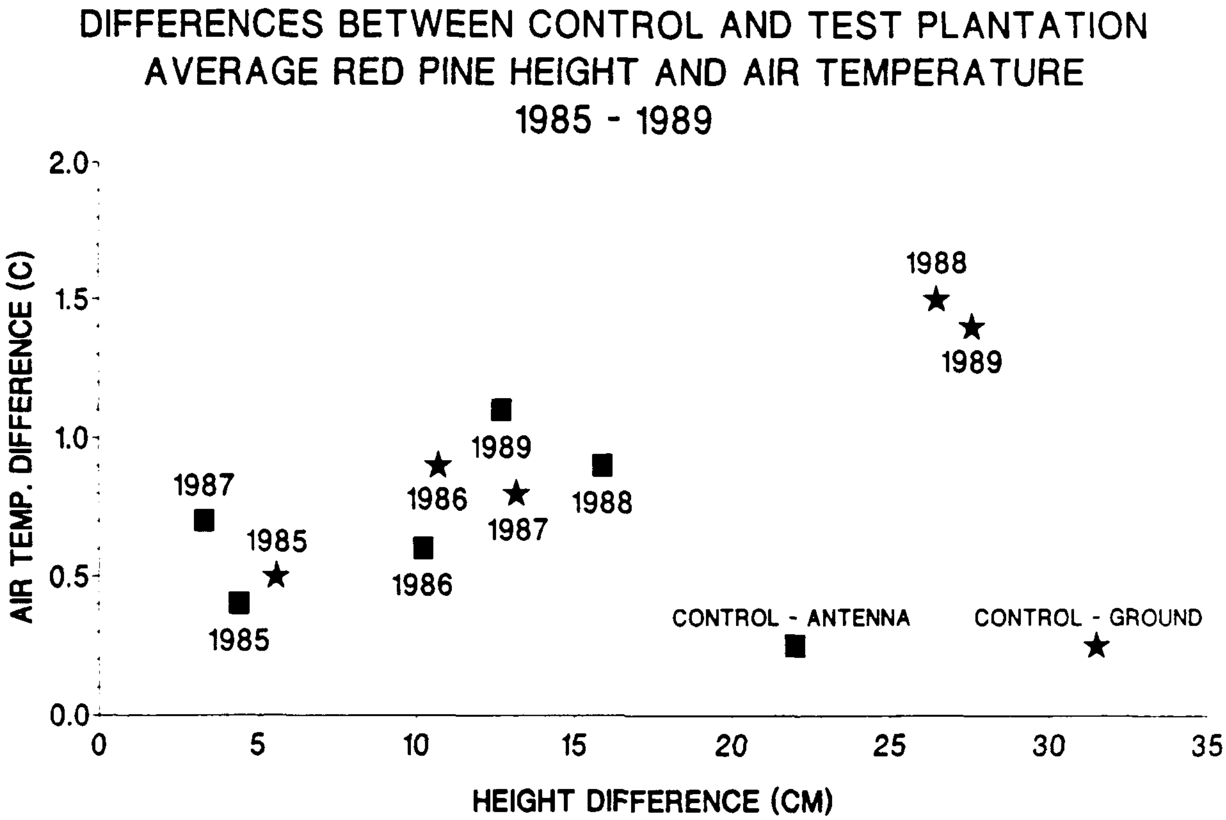
	Average Air Temperature (°C) Control & Antenna	
	Plantation	**Hardwoods**
1985	11.7 a[1]	11.8 a
1986	12.4 a	12.4 a
1987	13.2 a	13.1 a
1988	13.4 a	12.9 b
1989	12.6 a	12.2 b

1/ Stand types for a given year with the same letter are not significantly different ($p=.05$)

Given the close proximity of the antenna and ground sites, the stable relationship of air temperature at the control and antenna hardwood stands, and the annually increasing temperature of the control and antenna plantations relative to the hardwood stands, it is evident that factors other than regional climatic patterns are responsible for the increasing temperatures at the control plantation compared to the ground site plantation. It would also indicate that the changes in temperature during the period have occurred in the plantations rather than the hardwood stands.

The changes in the relationship between the air temperatures at the test sites and control site as well as the plantations and hardwood stands appears to be related to the increased amounts of red pine biomass in the plantation. Table 1.5 shows the increasing trends of average height and basal diameter of red pine at the three sites over the last five years. The increased height and diameter also reflect the increased foliage biomass and leaf area at the sites. Vegetation biomass absorbs and stores short and long wave

Figure 1.4



DIFFERENCES BETWEEN CONTROL AND TEST PLANTATION
AVERAGE RED PINE HEIGHT AND AIR TEMPERATURE
1985 - 1989
AIR TEMP. DIFFERENCE (C)
2.0
1.5
1.0
0.5
0.0
0
5
10
15
20
25
30
35
HEIGHT DIFFERENCE (CM)
1988
1989
1989
1987
1986
1987
1988
1985
1986
1985
CONTROL - ANTENNA
CONTROL - GROUND

radiation and then reradiates this energy as long wave radiation. At times of low heat loss from evaporation and convection, temperatures in the air near the surface of the

Table 1.5 Average height (cm) and basal diameter (cm) of the red pine at each site.

	Ground		Antenna		Control	
Year	Diam.	Ht.	Diam.	Ht.	Diam.	Ht.
1985	0.74	22.7	0.70	23.9	0.79	28.3
1986	1.28	37.3	1.26	40.3	1.36	50.5
1987	1.88	59.2	2.12	66.6	2.12	69.9
1988	2.43	90.2	2.79	100.8	2.71	116.7
1989	3.38	131.4	3.80	146.3	3.71	159.0

canopy can be as much as $4^{o}c$ warmer than ambient air (Larcher 1983). The increased differences in temperatures between the plantations and hardwoods appear to reflect the increased amounts of biomass available for radiation absorption and the decreased distance between the air temperature sensors and red pine canopy in the plantations. As the canopy surface of the plantations continues to approach the height of the air temperature sensors, the temperatures of air at the 2 m height should continue to increase. Increased temperatures at the control plantation compared to the test sites appears to be related to the higher productivity of this plantation. Figure 1.4 shows that as the differences in height between the control and test plantations increased, differences in the average air temperature at the sites also increased. This appears to be related to the decreased distance of the control plantation canopy to the height of the air temperature sensor as well as the increased red pine biomass at the control in relation to the test site.

Summary: Air temperature at the control site has been found to be significantly higher than at the test site during each year of the study. These results demonstrate that either differences in regional climate or local topography exist between the sites. Although differences in air temperature between the hardwood stands at the control and antenna sites have remained stable over the period of the study, air temperature at the control plantation has increased relative to the test site plantations. These changes in air temperature are related to the greater productivity of the control plantation compared to the test site plantations. If ELF antenna operation has altered the productivity of the red pine on the test sites, air temperature is likely to have been affected as well. However until such differences in

productivity are documented, we will not be able to conclude that ELF fields have affected air temperature in this manner.

Soil Temperature

Soil temperature like air temperature has a direct influence on plant physiological processes such as cell division and elongation. However soil temperature also indirectly influences plant growth by affecting permeability of roots and thus water uptake (Kramer 1983), biological decomposition and availability of nutrients (Brady 1974). Climatic conditions or stand characteristics such as insolation, air temperature, and precipitation as well as soil characteristics are the main factors controlling soil temperatures. Thus possible changes in vegetation or soil properties (organic matter content etc.) due to ELF antenna operation could have a major effect on soil temperature. These effects would appear to be more dramatic in the hardwood stands where microclimate is influenced to greater degree by vegetation than it is in the younger plantation stands.

Soil Temperature (depth of 5cm)

Site comparisons: Differences between average daily soil temperatures (5 cm) during the growing season at the control and test plantations were less than 0.5 C^{o} during each year of the study except 1989 (Table 1.6). Although average monthly soil temperatures during the past five years were consistently warmer at the control hardwoods than the antenna hardwoods, average monthly temperatures at the control plantations were generally cooler than soils at the antenna and ground during April and May (Figures 1.5-1.6).

Average soil temperatures (5 cm) during the growing season were consistently warmer at the control than at the test sites. However, ANOVA tests showed no significant differences in soil temperatures between the control and antenna ($p=0.238$) or the control and ground ($p=0.094$).

Site by stand type interactions were also not found to be significantly different for the control vs antenna comparisons ($p=0.109$). This indicates that at present differences between soil temperatures at the hardwood and plantation stands are similar at the control and antenna sites.

Annual Comparisons: Differences among years were significant ($p<0.001$) for both site comparisons. Multiple range tests showed that average soil temperatures (5 cm) in 1986-1988 were significantly warmer than soil temperatures

AVERAGE MONTHLY SOIL TEMPERATURES 5cm
(1985-1989)

Figure 1.5

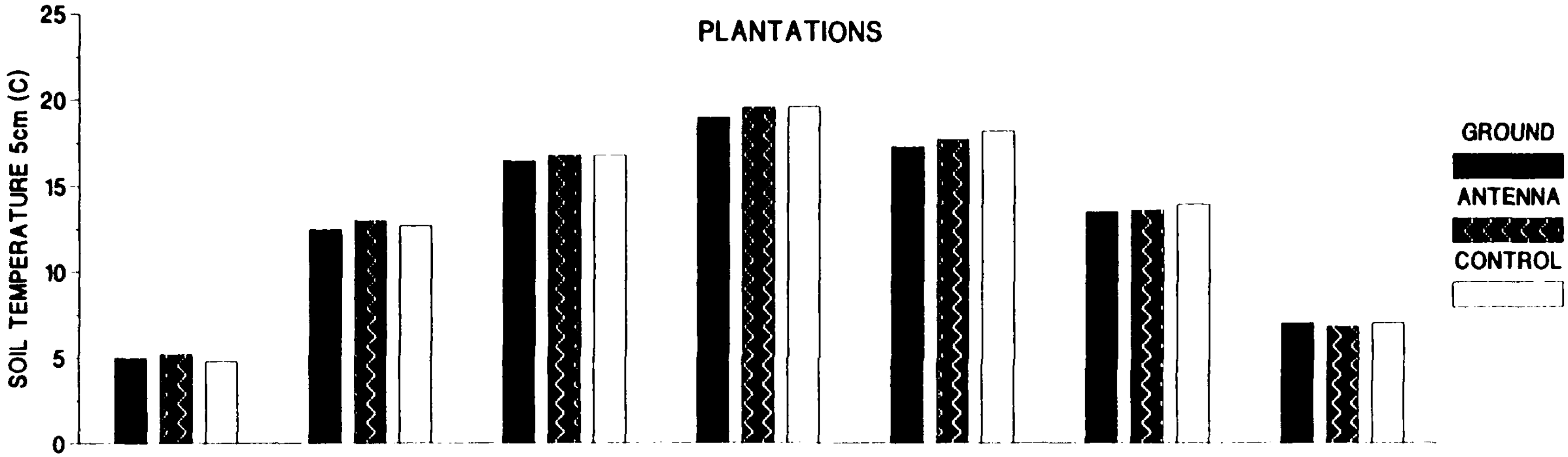


Figure 1.6

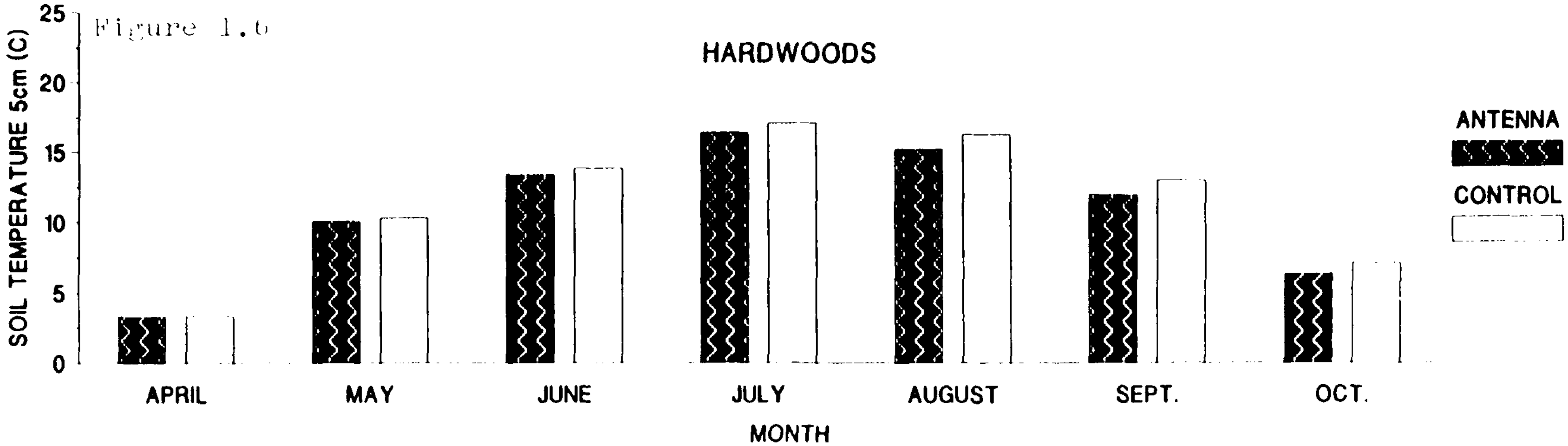


Table 1.6 Comparison of mean soil temperature (5cm) during the 1985-89 growing seasons (April-Oct).

Plantation

	Ground	Antenna	Control	Control-Ground	Control-Antenna
1985	12.5	12.9	12.5	0.0	-0.4
1986	13.3	13.5	13.5	0.2	0.0
1987	13.4	13.7	13.6	0.2	-0.1
1988	13.2	13.5	13.7	0.5	0.2
1989	12.3	12.6	13.2	0.9	0.6
Ave.	13.0	13.2	13.3	0.3	0.1
			Hardwoods		
1985		10.1	10.8		0.7
1986		11.2	11.7		0.5
1987		11.8	12.3		0.5
1988		11.2	11.6		0.4
1989		10.6	11.1		0.7
Ave.		11.0	11.5		0.5

Site Comparison

Control[1]	Ground
13.3 a	13.0 a
Control	**Antenna**
12.4 a	12.1 a

Annual Comparison

	Control & Ground	Control & Antenna
1985	12.5 b	11.6 d
1986	13.4 a	12.5 b
1987	13.6 a	12.9 a
1988	13.5 a	12.5 b
1989	12.7 b	11.9 c

1/Sites or year comparisons with the same letters for a specific site combination are not significantly different (p=0.05)

All values expressed in °C

in 1985 or 1989 (Table 1.6). However, multiple range tests ranked average annual soil temperatures from the control vs antenna comparison in the following manner : 1987>(1988=1986)>1989>1985. Differences in annual results from the two comparisons reflect a greater fluctuation of soil temperatures in the hardwood stands compared to the plantations. Soil temperatures in the hardwood respond to annual fluctuations of air temperature to a much greater degree than the plantations due to the greater insolation of the canopy in the hardwood stands compared to the plantations.

Site by Year Comparisons: Site and year interactions were not significant for the control vs. antenna site comparison (p=0.338) or the control vs. ground site comparison (p=0.060). Site by year by stand type interactions were also not significant (p=0.534). However temperatures at the control plantation over the past two years have appeared to increase relative to the test sites. Soil temperatures at the control plantation have increased between 0.6°C and 0.7°C relative to soil temperatures at the ground and antenna plantations since 1987. The trend of increasing soil temperatures at the control plantation are similar to the trend of increasing air temperature at the control plantation. Differences in soil temperatures between the control and test plantations would appear to be related to the greater productivity of the red pine at the control site.

Detection Limits: Detection limits associated with the site factor for the control vs ground comparison increased greater than 20% in this year's analysis. The detection limit was 0.27°C (Mroz et al. 1989) in last years analysis and increased to 0.36°C in this year's analysis.

Soil Temperature (depth 10cm)

Site Comparisons: Average soil temperatures (10cm) at the control site were within 0.7°C and 0.6°C of the average soil temperatures (10cm) at the test site plantations and hardwood stand respectively throughout the study period (Table 1.7). Comparisons of the sites using ANOVA tests showed no significant differences between the control and antenna sites (p=0.209) or the control and ground sites (p=0.167). Although average temperatures in all years except 1987 were greater at the control than at the antenna hardwood stand, the site by stand type interaction term was not significant (p=0.260).

Annual Comparisons: ANOVA tests indicated significant differences among years for all site comparisons (p<0.001). Multiple range tests (p=.05) ranked the annual average soil

Table 1.7 Comparison of soil temperature (10cm) during the 1985-89 growing seasons (April-Oct).

Plantation

	Ground	Antenna	Control	Control-Ground	Control-Antenna
1985	12.2	12.6	12.4	0.2	-0.2
1986	13.0	13.4	13.3	0.3	-0.1
1987	13.2	13.5	13.6	0.4	0.1
1988	13.3	13.2	13.2	-0.1	0.0
1989	12.0	12.5	12.7	0.7	0.2
Ave.	12.7	13.0	13.0	0.3	0.0
			Hardwoods		
1985		10.1	10.7		0.6
1986		10.9	11.4		0.5
1987		11.7	11.5		-0.2
1988		11.0	11.3		0.3
1989		10.3	10.9		0.6
Ave.		10.8	11.2		0.6

Site Comparison

Control[1]	Ground
13.0 a	12.7 a
Control	**Antenna**
12.1 a	11.9 a

Annual Comparison

	Control & Ground	Control & Antenna
1985	12.3 b	11.4 c
1986	13.1 a	12.3 b
1987	13.4 a	12.6 a
1988	13.3 a	12.2 b
1989	12.3 b	11.6 c

1/Sites or year comparisons with the same letters for a specific site combination are not significantly different (p=0.05)

All values expressed in °C

temperatures for the control vs antenna comparison in the following order: 1987>(1988=1986)>(1989=1988) (Table 1.7). Multiple range tests for the control vs ground analysis had similar results except 1987 was not significantly warmer than 1988 or 1986. Differences in the results of the multiple range test for the different comparisons were similar to those found for soil temperature at 5 cm.

Site by Year Comparisons: No significant differences were found for site by year interactions for the control vs antenna (p=0.372) or control vs ground comparisons (p=0.171). However, differences between sites during the study period were more apparent when stand types are considered separately. Table 1.7 shows that average soil temperature (10cm) was 0.6^{o}C warmer at the control hardwood stand than at the antenna hardwood stand type during 1985, 1986, and 1989, 0.2^{o}C cooler in 1987, and then 0.3^{o}C warmer in 1988. This variation in part appears to be related to the annual trends in temperature at the sites. Difference between the sites were greatest during the coolest years (1985,1986, and 1989) and least during the warmest year of the study (1987). These trends were not as apparent for comparisons of the control and antenna plantations. Furthermore no significant differences were found for the site by stand type by year interactions (p=.260). Thus if these trends actually exist they represent temperature variations that are less than the detection limits of our design.

Summary: This year's comparisons do not indicate that the present levels of ELF exposure have affected soil temperature at depths of 5cm or 10cm. This conclusion is based on: 1) differences between sites were not significant at p=.05, 2) although differences between years were significant, site by year interactions were not different, and 3) site by year by stand type interactions were not significantly different.. Although the soil temperatures at this time do not indicate any ELF effect, soil temperatures at a depth of 5 cm during the past two years have increased at the control plantation relative to the antenna and ground plantations. These trends of increasing soil temperature at the control plantation are similar to trends of increasing air temperature at this site and stand type. The changes in soil temperature like air temperature are most likely related to increased biomass of red pine occupying the plantations over the duration of the study as well as the greater productivity of the control plantation compared to the test site plantations. Continued changes in soil temperature are expected in the plantations as the canopy of the red pine continues to expand and the amount of radiation reaching the soil is reduced. Thus effects of EM fields on soil temperature can only be determined after the effects of these fields on the growth and productivity of red pine have been determined.

Soil Moisture

The amount and availability of water is a key factor in determining forest site productivity. The importance of water to plant growth should not be underestimated since almost all plant processes are influenced by the supply of water (Kramer 1983). Water in the soil is the primary media for transportation of nutrients within plants and is a reagent in photosynthesis. Apical and radial growth of trees have been shown to be highly correlated to soil water supplies (Zahner 1968).

Soil moisture is measured in the field and expressed as a percent of the dry soil weight at a given depth. Although moisture content gives a valuable measurement of the amount of water contained in the soil, it does not reflect to what degree plants can utilize this water. The tension at which water is held in the soil or soil water potential determines the availability of water to plants.

Given a specific moisture content, the availability of water can vary depending on soil characteristics. Thus soil water potential may give a more sensitive estimate of moisture relationships among the sites and years with respect to vegetation growth and productivity. Soil water potential values were estimated from equations relating soil moisture content at each plot to soil water potential (Appendix C 1987 Herbaceous Plant Cover and Tree Studies Annual Report). These equations were then applied to daily average soil moisture content at each depth at each plot.

Last year it was demonstrated that soil water potential was not normally distributed and may not be appropriate for parametric statistical tests. A natural log inverse transformation was applied to each soil moisture potential observation in an attempt to normalize the data. Although this transformation improved the normality of the data, distribution tests still rejected the normality hypothesis. This year work has been done to determine a nonparasitic test which would be compatible with the current experimental design. Freedman Rank Sum tests appear to be an adequate alternative to the ANOVA tests used thus far. Use of this test requires the use of weekly medians instead of averages. At this time the data haven't been modified and thus analysis of soil moisture potential were performed using parametric procedures on the transformed data as was done last year. This year average site, year, and other specific factor soil water potential values were determined from the mean transformed values of this factor rather than from the untransformed data.

Soil Moisture Status(depth 5cm)

Site Comparisons: Average soil moisture content (5cm) over the past four years has been higher at the control site than at the two test sites (Table 1.8). These differences were significant for both the control vs antenna (p=0.002). and the control vs ground (p=0.035) comparisons. Moisture content (5cm) was on the average 2.6% and 1.3% higher at the control than at antenna and ground sites respectively. Since the control site receives less precipitation than the test sites (Table 1.10), differences in moisture content at the sites appear to be related to the greater water holding capacity of the soils at the control compared to the test sites.

The site and stand type interaction was also found to be significant (p=0.015) for the control vs antenna comparisons. Multiple range tests showed that moisture content was significantly higher (p=0.05) at the control plantation than at the control hardwood stand while differences between stand types were not significant at the antenna site. Differences in the relationship between stand types of the two sites appears to be related to the moisture content at the plantation in 1986. This year was the only year during the study that moisture content was lower in the antenna plantation than in the antenna hardwoods. Differences between average moisture content in the two stand types were also the lowest during 1986 at the control site (Table 1.8). The differences in soil moisture relationships between the two stand types during 1986 may be related to some residual effect from initial stand harvesting and prior to plot establishment.

Differences in soil water potential were not significant for the control vs ground (p=0.548) comparison but were significant for the control vs antenna comparison (p=0.006). Although soil moisture content was greater at the control site than the antenna site, average soil water potential was lower (more negative) at the control compared to the antenna site. This indicates that although more water was present at the control site than at the antenna site, availability of soil water was greater at the antenna than at the control.

Annual Comparisons: Annual differences in soil moisture content were significant (p=0.05) for all site comparisons. Differences in soil water potential were significant for the control vs antenna comparison (p=0.007) but not significant for the control vs ground comparison (p=0.094). Although multiple range tests indicate that soil moisture content for both comparisons were higher in 1986 than in the following years, total precipitation received during 1986 was less than during 1987 and 1988 (refer to precipitation section). The higher moisture contents during 1986 appear to be related to the distribution and timing of precipitation during the year rather than the total amount

Table 1.8 Comparison of soil moisture content (%) and soil water potential(-mpa) at a depth of 5cm during the 1986-89 growing seasons (April-Oct).

	Ground		Antenna		Control		Control-Ground		Control-Antenna	
	%	-mpa	%	-mpa	%	-mpa	%	-mpa	%	-mpa
Plantation										
1986	13.2	.024	9.2	.022	16.0	.013	2.8	-.011	6.8	-.009
1987	13.6	.022	11.3	.013	13.5	.018	-0.1	-.004	2.2	.005
1988	11.8	.029	11.3	.016	12.9	.024	1.1	-.005	1.6	.008
1989	13.0	.018	10.9	.014	14.2	.020	1.2	.002	3.4	.006
Ave.	12.9	.023	10.6	.016	14.2	.018	1.3	-.005	3.6	.002
Hardwoods										
1986			10.4	.024	14.1	.024			3.7	.000
1987			10.8	.023	10.9	.031			0.1	.008
1988			9.5	.026	10.6	.046			1.1	.020
1989			9.5	.023	11.2	.046			1.7	.023
Ave.			10.1	.024	11.7	.036			1.8	.008

Site Comparison

	Control[1]	Ground
Moisture Content	14.2 a	12.9 b
Soil Water Pot.	.018 a	.023 a
	Control	**Antenna**
Moisture Content	12.9 a	10.3 b
Soil Water Pot.	.025 a	.019 b

Annual Comparison

	Control & Ground		Control & Antenna	
	%	-mpa	%	-mpa
1986	14.6 a	.018 a	12.4 a	.020 b
1987	13.6 b	.020 a	11.6 b	.021 b
1988	12.3 b	.027 a	11.1 b	.026 a
1989	13.6 b	.018 a	11.4 b	.024 a

1/Sites or year comparisons with the same letters for a specific site combination are not significantly different (p=0.05)

of precipitation. The amount of precipitation received in March and April of 1986 and the amount of water in the snowpack in 1986 was greater than the amounts of precipitation from these sources in 1987 through 1989. Total amount of precipitation during September and October of 1986 was also greater than the amount of precipitation during these two months in 1987 and 1989. Although amounts of precipitation and soil moisture content at the sites during June, July, and August of 1986 were below normal, the higher levels of precipitation in the spring and fall tended to increase average moisture contents during the growing season above the levels in 1987-1989.

Site by Year Comparisons: Site by year interactions were significant for both moisture content ($p<0.001$) and soil water potential ($p=0.014$) in the control vs antenna comparisons. However site by year interactions were not significant for the control vs ground comparison. Multiple range tests showed that the antenna site was dryer than the control site each year of the study (Table 1.9). However, differences in moisture content or soil water potential between the sites did not consistently increase or decrease over the duration of the study. For example differences in average moisture content at the two sites were greatest in 1986 but were also greater in 1989 than in 1987 or 1988 (Table 1.9). Since no consistent trend is evident in the soil moisture relationships between the control and antenna sites during the study period, changes in moisture contents do not appear to be related to ELF antenna operation.

Site by year by stand type interactions were also not significant for soil moisture content ($p=0.084$) and soil water potential ($p=0.904$). These results also indicate that the ELF antenna operation has not caused a detectable change in soil moisture at the sites.

Table 1.9. Soil moisture content (5cm) for control and antenna sites for each year.

	Control	Antenna	Control-Antenna
1986	15.0 a[1]	9.8 e	5.2
1987	12.2 b	11.1 cd	1.1
1988	11.7 bc	10.4 de	1.3
1989	12.7 b	10.2 de	2.5

/1 Site and years with the same letters not significantly different ($p=0.05$).

Detection Limits: Soil moisture content detection limits, with the exception of the site factor for the control vs ground comparison, were within 20% of the values determined last year. This year the detection limit associated with site for the control vs ground comparison was 0.48 compared to 1.82 reported last year. It appears that the detection limit was computed inaccurately last year. Detection limits were also not accurately computed for the transformed soil water potential measurements last year. The detection limits are presented in Table 1.10. Detection limits associated with soil water potential are still 50 to 200% greater than detection limits calculated from moisture contents for the same factors and comparisons.

Table 1.10. Detection limits (p=.05) associated with year and site factors for soil moisture content (10 cm) and soil moisture tension (10 cm).

Factor	Detection Limits Log. Inv.[1] Soil Wat. Pot.	% Mean Log Inv. Soil Wat. Pot.
Site (Control vs Ground)		
Site	.178	11.2
Year	.400	25.1
Site x Year	.566	35.6
Site (Control vs Antenna)		
Site	.188	12.5
Year	.237	15.7
Site x Year	.341	22.6
Site x Stand Type	.553	36.7
Site x Stand Type x Year	.489	32.4

[1] Natural logarithm inverse soil water potential

Soil Moisture Status (depth 10cm)

Site Comparisons: Site relationships regarding soil moisture content at 10cm were similar to site relationships involving soil moisture content at depths of 5cm. Moisture contents at 10cm were consistently higher at the control site than at the test sites (Table 1.11). However, differences between sites were only significant for the

Table 1.11 Comparison of soil moisture content (%) and soil water potential(mpa) at a depth of 10cm during the 1986-89 growing seasons (April-Oct).

Plantation

	Ground		Antenna		Control		Control-Ground		Control-Antenna	
	%	-mpa	%	-mpa	%	-mpa	%	-mpa	%	-mpa
1986	15.2	.018	9.2	.018	14.6	.017	-0.6	-.001	5.4	-.001
1987	14.2	.016	9.8	.014	15.1	.014	0.9	-.002	5.3	.000
1988	12.9	.021	10.3	.018	14.4	.019	1.5	-.003	4.1	.001
1989	14.0	.016	10.7	.013	14.4	.020	1.4	.004	3.7	.007
Ave.	14.1	.018	10.0	.016	14.6	.017	0.5	-.001	4.6	.001
					Hardwoods					
1986			10.0	.023	12.6	.025			2.6	.002
1987			11.2	.022	12.7	.021			1.5	-.001
1988			10.5	.019	12.8	.021			2.3	.002
1989			9.8	.022	11.1	.031			1.3	.009
Ave.			10.4	.021	12.3	.024			0.9	.003

Site Comparison

	Control[1]	Ground
Moisture Content	14.6 a	14.1 a
Soil Water Pot.	.017 a	.018 a
	Control	**Antenna**
Moisture Content	13.5 a	10.2 b
Soil Water Pot.	.020 a	.018 a

Annual Comparison

	Control & Ground		Control & Antenna	
	%	-mpa	%	-mpa
1986	14.9 a	.017 a	11.6 a	.020 a
1987	14.7ab	.018 a	12.2 a	.017 a
1988	13.6 b	.021 a	12.0 a	.019 a
1989	14.2ab	.023 a	11.5 a	.020 a

[1]/Sites or year comparisons with the same letters for a specific site combination are not significantly different (p=0.05)

control vs antenna comparison (p=.005). Differences in soil water potential were not significant for the control vs ground comparison (p=0.915) or the control vs antenna comparison (p=0.298).

Differences in moisture content (10cm) between the control and antenna sites in the hardwoods were less than differences between these two sites in the plantation stand type. Significant site by stand type interactions (p=0.035) were also found for soil moisture content at this depth. Results from multiple range tests showed similar trends to those from depths of 5 cm. Moisture content at the control plantation was significantly (p=0.05) higher than at the control hardwood stand but moisture content at the antenna plantation was not significantly greater than at the antenna hardwood stand. Average moisture contents, although not significantly, have actually been higher in the hardwood stand compared to the plantation stand at the antenna site. Although moisture content is greater in the plantation than in the hardwoods at the antenna, soil water potential is lower (more negative) in the hardwood compared to the plantation stand type. Differences between the soil water potential of the two stand types indicate that as expected availability of water is lower in the fully stocked hardwood stand compared to the developing red pine plantation.

Annual Comparisons: ANOVA tests showed significant differences in soil moisture content between years (p=0.009) for the control vs ground comparison and the control vs antenna comparisons (p=0.032). Multiple range tests for the control vs ground comparisons ranked moisture contents in 1986 significantly higher than moisture content in 1988. Multiple range tests did not show any differences between years for the control vs antenna comparisons. No significant differences in soil water potential among years for either comparison were evident in this years analysis.

Site by Year Interactions: ANOVA tests for the control vs ground and control vs antenna comparison showed no significant site by year interactions for soil moisture content (p=0.367 control vs ground, p=0.185 control vs antenna). ANOVA tests involving soil water potential showed similar results with nonsignificant differences for the control vs ground (p=0.480) or control vs antenna (p=0.068) comparisons. Site by year by stand type interactions were also not significant (p=0.05) for moisture content and soil water potential. Thus it appears moisture relations among sites at this depth have remained stable over the study period.

Detection Limits: Soil moisture content and soil water potential detection limits decreased greater than 20% of last

years values for site factors in the control vs ground comparisons. Detection limits for soil moisture content and soil water potential were respectively .387 and .233 this year compared to 1.74 and .686 last year.

Summary: At this time no detectable effects of EM fields on soil moisture content and soil water potential are apparent at the test sites. This conclusion is based on the following results and observations: 1) moisture status although significantly different among sites and years show no consistent trends related to increasing levels of ELF antenna operation 2) changes in the relationship of soil moisture regimes among the sites during the study period appear to be related to climatic factors such as precipitation rather than treatment effects 3) although differences in soil moisture regimes of the two stand types are not consistent at the control and antenna site, these differences have been stable over the duration of the study and appear to be related to inherent variability within the sites and not to the operation of the ELF antenna.

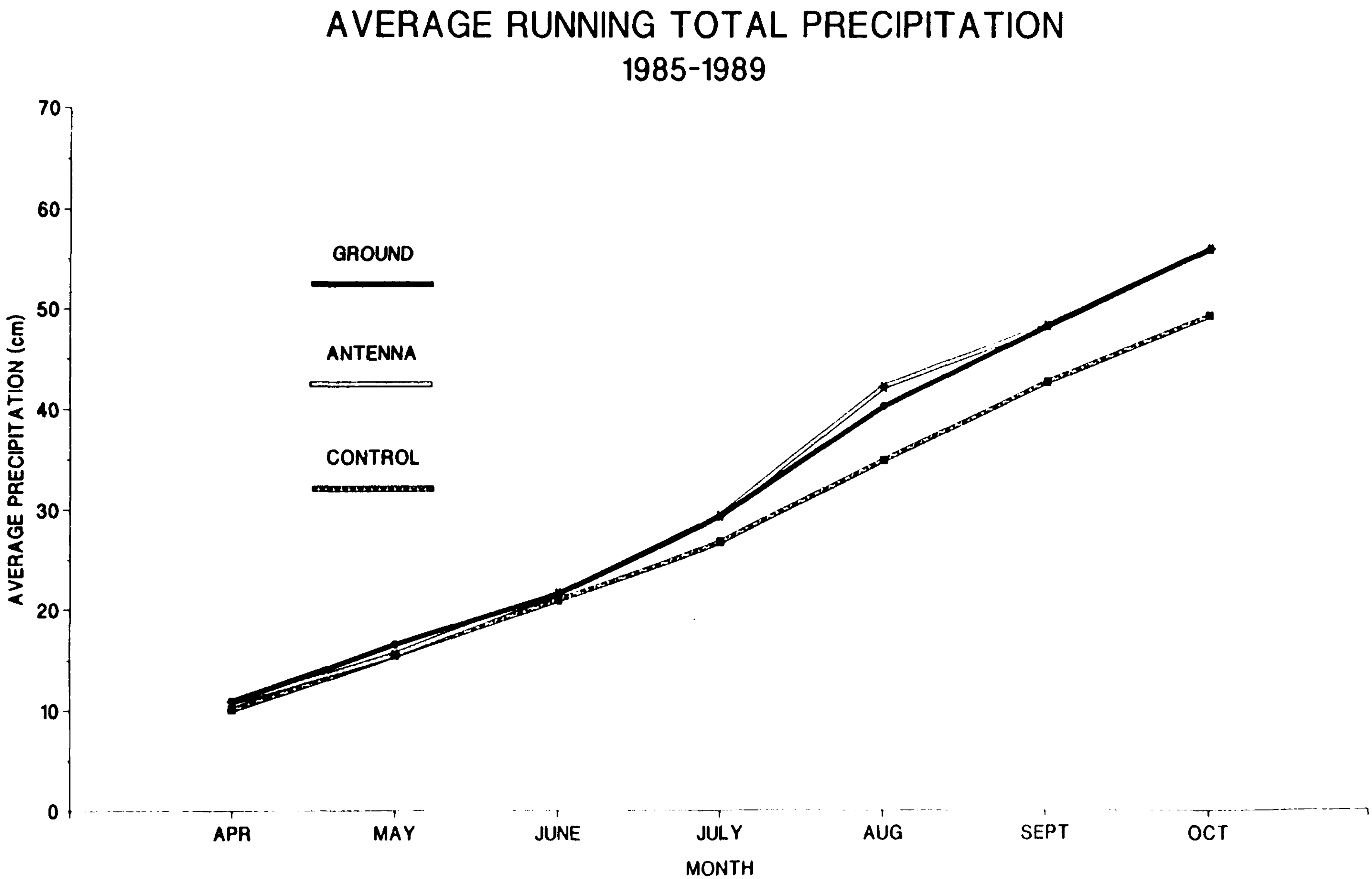
Precipitation

The amount of precipitation and the distribution of precipitation over time are two primary factors controlling availability of water for plant growth. Thus precipitation is an important factor in the climatic monitoring program.

Site Comparisons: Total amount and distribution of precipitation has been similar among sites during the study period (Figure 1.7) However during the five year study period the control site has averaged 6.7 cm less precipitation than the antenna or ground site. The majority of this deficit occurs during July and August (Figure 1.8). During these two months the ground and antenna site have received respectively 4.3 and 4.6 cm more precipitation than the control. Although the test sites have received on the average 15.4% more precipitation each week than the control site, ANOVA tests showed no significant differences between average weekly amounts of precipitation at the control and ground (p=0.377) or the control and antenna sites (p=0.406). The failure of the ANOVA tests to indicate significant differences between the sites is in part related to the high detection limits associated with precipitation.

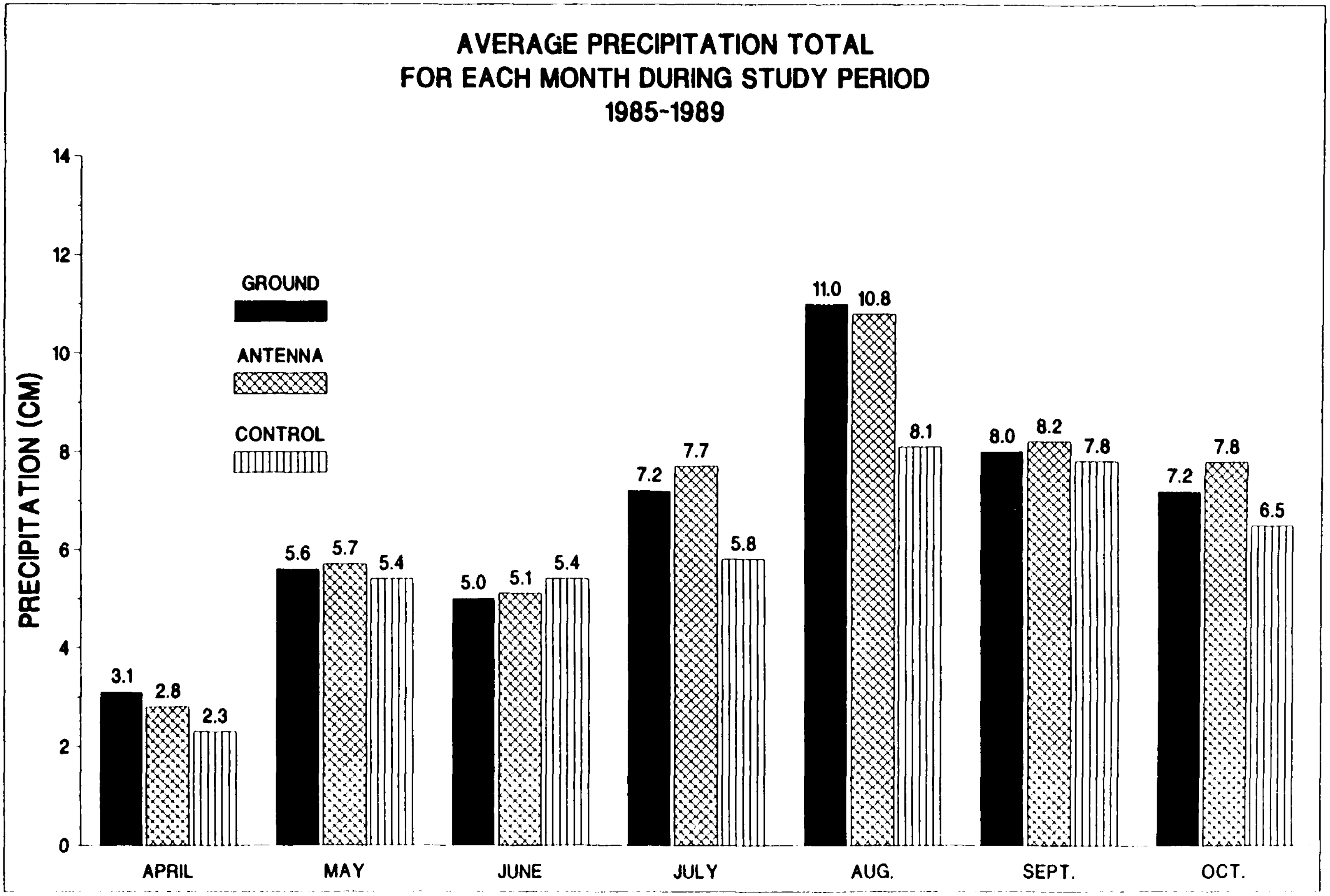
Annual Comparisons: Average weekly precipitation in 1985 to 1989 at the sites were between 1.72 and 1.49 (Table 1.12). Average weekly precipitation during the growing season was lowest during 1986 and highest during 1985.

Figure 1.7



AVERAGE RUNNING TOTAL PRECIPITATION
1985-1989
GROUND
ANTENNA
CONTROL
AVERAGE PRECIPITATION (cm)
0
10
20
30
40
50
60
70
APR
MAY
JUNE
JULY
AUG
SEPT
OCT
MONTH

Figure 1.8



AVERAGE PRECIPITATION TOTAL
FOR EACH MONTH DURING STUDY PERIOD
1985-1989
PRECIPITATION (CM)
14
12
10
8
6
4
2
0
GROUND
ANTENNA
CONTROL
3.1
2.8
2.3
5.6
5.7
5.4
5.0
5.1
5.4
7.2
7.7
5.8
11.0
10.8
8.1
8.0
8.2
7.8
7.2
7.8
6.5
APRIL
MAY
JUNE
JULY
AUG.
SEPT.
OCT.

Table 1.12 **Comparison average precipitation amounts (cm) during the 1985-89 growing seasons (April-Oct).**

	Ground	Antenna	Control	Control-Ground	Control-Antenna
1985	2.41	2.46	1.97	-0.44	-0.49
1986	1.20	1.14	1.22	0.20	0.07
1987	1.78	1.87	1.78	0.00	-0.09
1988	1.80	1.77	1.49	-0.31	-0.28
1989	1.42	1.36	0.98	-0.44	-0.38
Ave.	1.72	1.72	1.49	-0.23	-0.23

Site Comparison

Control[1]	Ground
1.49 a	1.72 a

Control	Antenna
1.49 a	1.72 a

Annual Comparison

	Control & Ground	Control & Antenna
1985	2.22 a	2.19 a
1986	1.18 b	1.21 b
1987	1.82ab	1.78ab
1988	1.63ab	1.65ab
1989	1.11 b	1.20 b

[1]/Sites or year comparisons with the same letters for a specific site combination are not significantly different ($p=0.05$)

Total amount of precipitation (including amount of snow melt in March) was lower in 1989 than in 1986. Comparisons of monthly running totals for each year and the average monthly running total for the study period indicated that by the end of October total amounts of precipitation received at the control and antenna sites in 1989 were between 17 and 20 cm below five year study period averages (Figure 1.9-1.10). Precipitation at the ground site showed similar deficits.

ANOVA tests showed significant differences between years for the control vs ground ($p=0.022$) and control vs antenna comparisons ($p=0.014$). Multiple range tests indicated that

Figure 1.9

MONTHLY DEVIATION
FROM MEAN STUDY PERIOD RUNNING TOTAL PRECIPITATION
FOR EACH STUDY YEAR AT THE ANTENNA SITE

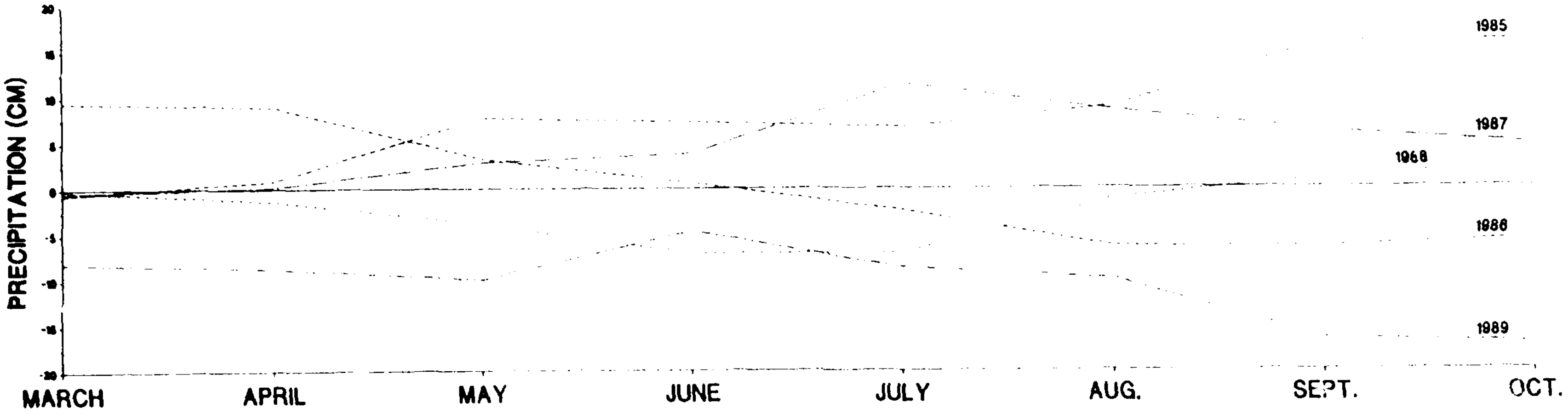
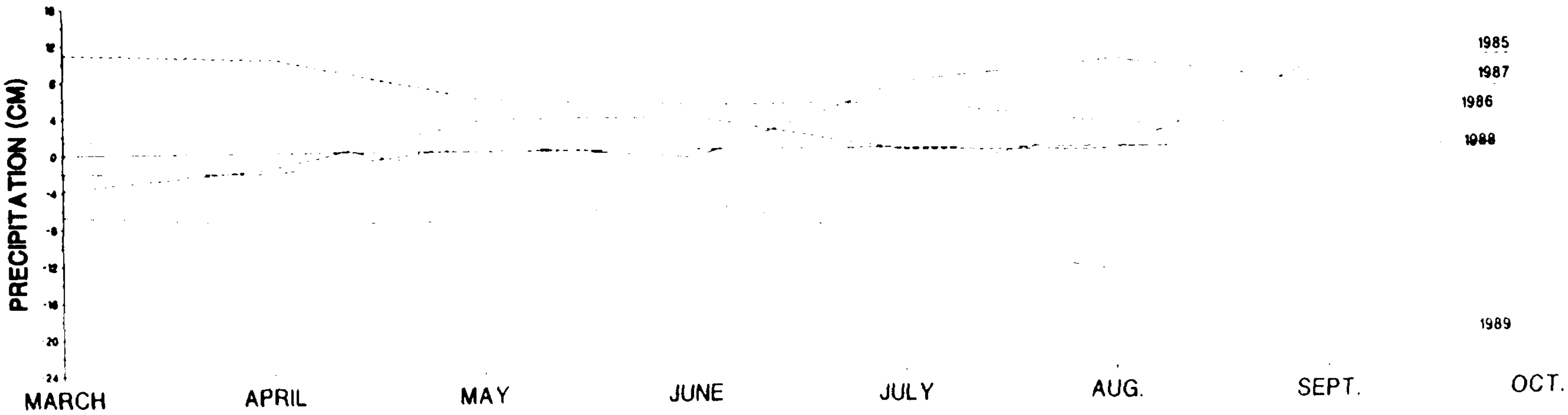


Figure 1.10

MONTHLY DEVIATION
FROM MEAN STUDY PERIOD RUNNING TOTAL PRECIPITATION
FOR EACH YEAR AT THE CONTROL SITE



precipitation was greater in 1985 than in 1986 or 1989 for both site comparisons (Table 1.12). All other year combinations were not significantly different (p=0.05).

Site by Year Comparisons: No significant differences were found for site by year interactions in either the control vs ground comparison (p=0.907) or the control vs antenna comparison (p=0.909).

Detection Limits: With exception of the site factors for both comparisons, detection limits were within 20% of the detection limits calculated last year. Detection limits associated with the site differences increased from 0.487 cm for the control vs ground and 0.493 cm for the control vs antenna comparison in 1988 to 0.612 cm and 0.617 cm respectively this year.

Summary: Precipitation collectors are located in a cleared section of the plantations and the amounts of rainfall collected are not affected by the vegetation at the plantation. Thus precipitation is considered to be independent of ELF effects and no discussion relative to ELF exposure is included with this section.

Global Solar Radiation

Solar radiation is the primary energy source for photosynthesis as well as the primary factor controlling climatic conditions. Thus solar radiation is continually monitored at the study sites.

Comparisons of global solar radiation did not include July of 1987 or April of 1988. Data from July of 1987 was not available due to the lightning strike at the ground site and the sensor was being calibrated during April of 1988. Thus it was felt that a more suitable comparison of yearly information could be made if April and July were excluded from the analyses.

Annual Comparisons: ANOVA tests were performed on only May, June, August, September, and October measurements due to sensor failure in July of 1987 and sensor calibration in April of 1988. Measurements of global solar radiation in August of 1988 were low because 16 days of measurements were missing due to a computer failure (Figure 1.11). Average daily global solar radiation during the adjusted 1985 and 1988 growing season were between 20 and 54 Langleys/day higher than in the years 1986-1988 respectively (Table 1.13). However differences between years were not significant (p=0.074).

Analyses in 1986 indicated significant year by month interactions. The analysis in 1986 included the month of July

because the solar radiation sensor was operational in July for both 1985 and 1986. This years analysis which

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Table 1.13 Average global solar radiation during the 1985-1987 adjusted growing seasons and detection limits for year and month by year factors (p=.05)

Global Solar Radiation[1/]
(Langleys/Day)

1985	**1986**	**1987**	**1988**	**1989**
385.1 a	360.9 a	364.6 a	331.0 a	383.2 a[2]

Factor	**Detection Limit (Langleys/Day)**	**% Mean**
Year	58.8	16.1
Year x Month	118.0	32.2

[1/] Averages and analysis using May-June, August-October. July was excluded from the analysis due to missing information from July 1987 and April 1988.

[2/] Years with the same letters are not significantly different (p=0.05).

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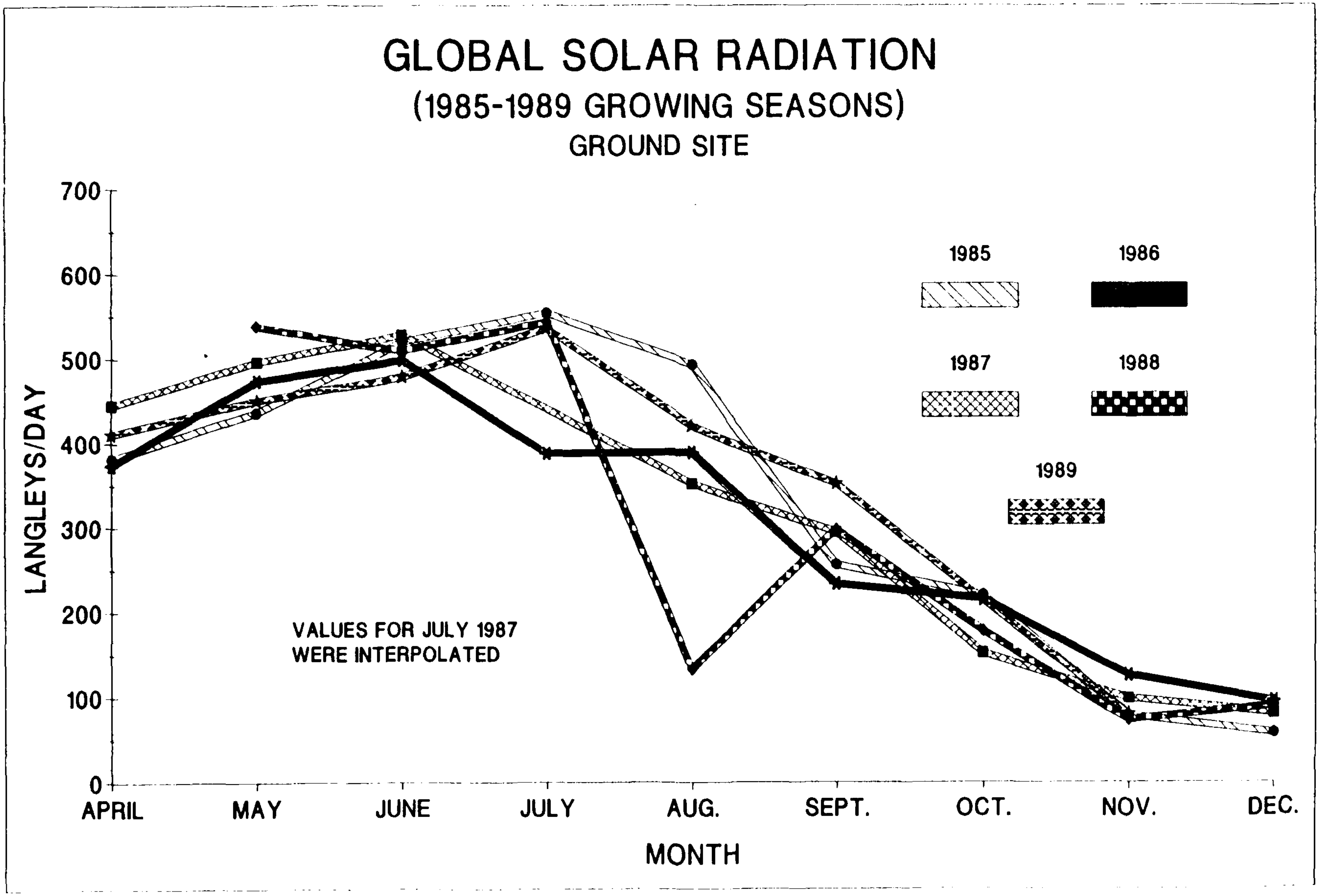
excluded this month did not find a significant month by year interaction (p=0.067). Global solar radiation is generally the highest in June and July (Figure 1.11). Thus missing observations from these two months appear to critically affect the outcome of the statistical analyses.

Detection Limits and Summary: The detection limit for the yearly comparison was less than 20% of the detection limit computed last year. The detection limit for this factor last year was 71.5 Langleys/day while the detection limit calculated this year was 58.5 Langleys/day. The detection limit for the year by month interaction was within the 20% of the value computed last year.

Summary: The global solar radiation sensor is located about 4 meters above the ground in the plantation at the

Figure 1.11



GLOBAL SOLAR RADIATION
(1985-1989 GROWING SEASONS)
GROUND SITE
LANGLEYS/DAY
700
600
500
400
300
200
100
0
APRIL
MAY
JUNE
JULY
AUG.
SEPT.
OCT.
NOV.
DEC.
MONTH
1985
1986
1987
1988
1989
VALUES FOR JULY 1987
WERE INTERPOLATED

ground site. Thus global solar radiation is independent of ELF fields.

Relative Humidity

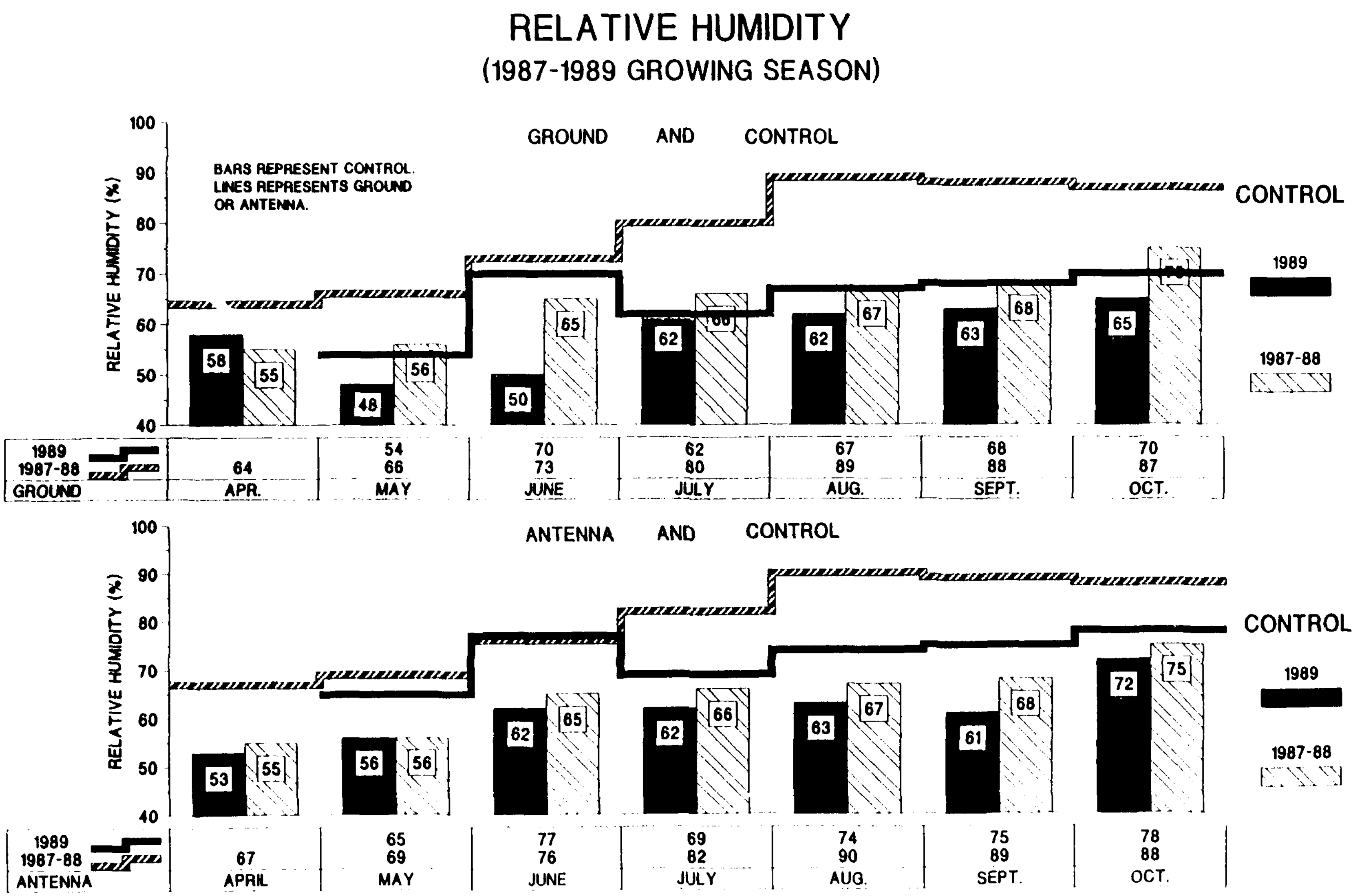
Atmospheric humidity is an influential factor determining rates of plant transpiration and respiration. Humidity is related to vapor pressure gradients which influence the amount of transpiration and evaporation from a given land area. In an attempt to fully monitor the climate at the study sites, relative humidity is measured by the ambient monitoring systems.

As a result of sensor repairs and system failures this is the third year that relative humidity has been monitored during the entire growing season. Thus annual comparisons and site comparisons are limited to 1987, 1988, and 1989. Inititation of relative humidity monitoring begins each year after snow melt. Generally there are only 14 to 21 days in April when relative humidity is monitored. In order to eliminate bias from comparisons of years or sites April, measurements were not included in this years analysis.

Site Comparisons: During the last three years relative humidity has been higher at the test sites than at the control site (Table 1.14, Figure 1.12). Differences were significant ($p=0.006$) for the control vs antenna and the control vs ground comparisons ($p=0.002$) Average differences during the past three years between the test and the control sites averaged 15.5% relative humidity for the control vs antenna comparison and 12.0% relative humidity for the control vs ground comparison. Differences in relative humidity between sites appears to be well related to the lower amounts of precipitation received at the control site compared to the test sites.

Annual Comparisons: Differences among average relative humidity for the three years were significant for the control vs antenna comparisons ($p=0.001$) and the control vs ground comparison ($p<0.001$). Multiple range tests ranked the average relative humidity for each year and site comparison in the following order 1987>1988>1989. Annual decreases in relative humidity generally reflected decreasing annual amounts of precipitation (refer to precipitation section). Differences in average relative humidity among years was between 4 and 9% relative humidity depending on the sites used for comparison.(Table 1.14).

Figure 1.12



RELATIVE HUMIDITY
(1987-1989 GROWING SEASON)
GROUND AND CONTROL
BARS REPRESENT CONTROL.
LINES REPRESENTS GROUND OR ANTENNA.
RELATIVE HUMIDITY (%)
100
90
80
70
60
50
40
58
55
48
56
50
65
62
62
67
63
68
65
CONTROL
1989
1987-88
1989
1987-88
GROUND
64
APR.
54
66
MAY
70
73
JUNE
62
80
JULY
67
89
AUG.
68
88
SEPT.
70
87
OCT.
ANTENNA AND CONTROL
53
55
56
56
62
65
62
66
63
67
61
68
72
75
ANTENNA
67
APRIL
65
69
MAY
77
76
JUNE
69
82
JULY
74
90
AUG.
75
89
SEPT.
78
88
OCT.

Table 1.14 Comparison of relative humidity during the 1987- and 1989 (May-Oct.) and detection limits associated with site and year factors (p=0.05).

Relative Humidity (1987-1989)

	Ground	Antenna	Control	Control-Ground	Control-Antenna
1987	81.0	84.1	70.0	-11.0	-14.1
1988	80.0	80.0	62.5	-17.5	-17.5
1989	65.9	73.1	58.3	-7.6	-14.8
Mean	75.6	79.1	63.6	-12.0	-15.5

Relative Humidity
%

Control	Ground
63.6 b	75.6 a[1]
Control	**Antenna**
63.6 b	79.1 a

	1987	1988	1989
Control vs Ground	75.5 a	71.2 b	62.1 c
Control vs Antenna	77.1 a	71.2 b	65.7 c

	Detection Limits %	% Mean
Control vs Antenna		
Site	2.56	3.58
Year	2.70	3.78
Year by Site	3.82	5.35
Control vs Ground		
Site	2.60	3.60
Year	2.67	3.76
Year by Site	3.78	5.32

1/ Year or site comparisons with the same letter for a specific site combination are not significantly different (p=0.05)

Site by Year Interactions: Site by year interactions were significant for the control vs ground comparisons ($p=0.020$) but were not significant for the control vs antenna comparisons ($p=0.700$). Multiple range tests ranked average relative humidity for each site and year in the following order : (Ground 88= Ground 87) > Control 87 > (Control 88 = Ground 89) > Control 89. Although site by year interactions were significant, differences between sites showed no consistent trend over the duration of the study (Table 1.14).

Detection Limits: Detection limits for all factors except site decreased more than 20% compared to last years detection limits. Site detection limits increased from 1.38 to 2.56% for the control vs antenna comparison and 1.94 to 2.60% for the control ground comparison.

Summary: Although significant site by year interactions were found for the control vs ground comparisons, the multiple range tests did not indicate any specific trend which could be related to increasing EM fields. Significant site by year interactions may have been caused by minor differences in sensor performance due to annual recalibration. Relative humidity sensors are located 2 meters above the ground at the same position as air temperature sensors. In the future increased canopy closure and height of the red pine may affect the measurement of relative humidity as if has affected the measurement of air temperature. However, at this time there has been no apparent affect of the canopies on relative humidity.

Photosynthetically Active Radiation (PAR)

Photosynthetically active radiation is measured in the hardwood stands at the control an antenna sites. This climatic variable should be sensitive to possible ELF related changes in the canopy of the hardwood stand. Reduction of foliage biomass or changes in the timing of leaf expansion or leaf fall would alter the amount of radiation reaching the forest floor over the duration of the growing season. This type of change would affect the growth of forest floor vegetation and the microclimate in the hardwood stands.

Sensor and system failures have limited the amount of months of data which can be used for this analysis. We have measurements for this variable for May through July of 1986-1989 and have used this data set for ELF effect testing. Measurements during this time span should give a good indication of any changes in leaf area or timing of leaf expansion between the control and test sites.

Site and Annual Comparisons: Comparisons of sites and years are limited to the months of May through July, due to the downtime of the platforms. Since PAR sensors were not operational until June of 1985, 1986 through 1989 are the only years used in PAR comparisons. Figure (1.13) shows that PAR is dramatically reduced during May and June when leaf expansion of the hardwood stands occur.

Averages PAR was 1.55 Einsteins/day higher at the antenna site than at the control site during 1986-1989. Average PAR has also decreased 1.13 Einsteins/day during the four years of measurements (Table 1.15). Neither differences between sites ($p=0.523$) or among years ($p=0.250$) were significant in this years analysis. Site by year factors were also not significantly different ($p=.922$) for this years analysis.

Detection Limits and Summary: Table (1.18) presents the detection limits for PAR. These values are similar to the limits calculated in 1987 and are indicative of ambient variables only measured on a site level.

Table 1.15. Comparison of photosynthetically active radiation during 1986 -1989 (May-July).

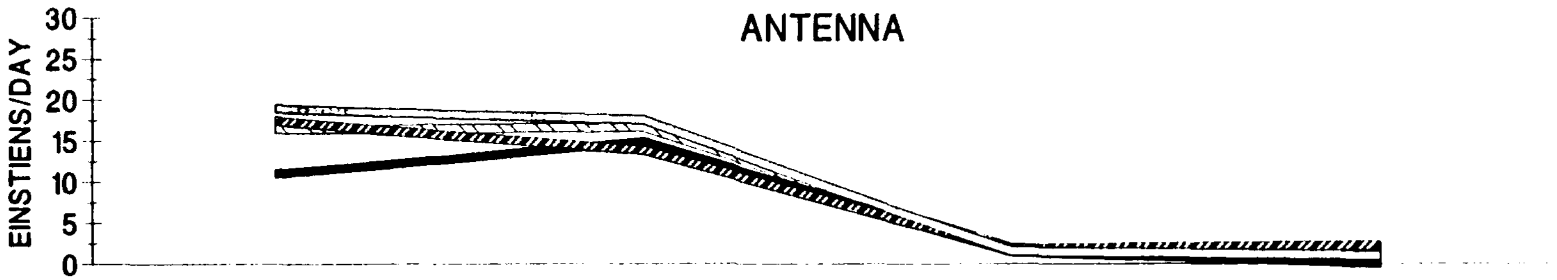
Average Daily PAR[1]/
(Einsteins/Day)

	1986	1987	1988	1989	$\bar{X}$
Control	4.77	5.06	4.53	3.27	4.41 a[1]
Antenna	6.33	5.83	6.10	5.56	5.96 a
Control-Antenna	-1.56	-0.77	-1.57	-2.29	-1.55
Average	5.55 a	5.45 a	5.31 a	4.42 a	

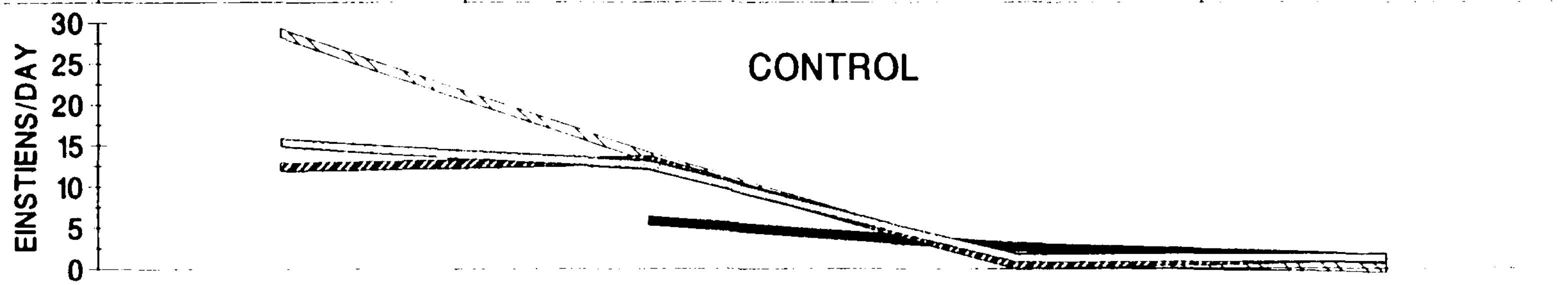
[1] Site or year comparison with the same letter are not significantly different at ($p=.05$).

Figure 1.13

PHOTOSYNTHETIC ACTIVE RADIATION
(1986-1989) GROWING SEASONS
(30 CM ABOVE GROUND IN HARDWOOD STAND TYPES)



1986	19.0	17.6	1.6	1.1
1987	17.5	13.9	1.9	2.3
1988	16.5	16.7	2.0	.8
1989	11.1	15.0	1.5	0.1
MONTH	APRIL	MAY	JUNE	JULY



1986	15.4	12.8	1.3	1.3
1987	12.4	13.2	.5	1.4
1988	28.7	13.6	.7	.1
1989		5.9	2.7	1.2
MONTH	APRIL	MAY	JUNE	JULY

Summary: Since no significant differences were found for the site, year, or site by year interactions, there was no evidence to indicate that the present levels of ELF exposure has affected PAR at the antenna hardwood site.

Air Temperature (30cm above ground)

Air temperature is being monitored 30cm above the ground to give a more accurate measurements of climatic conditions at the understory air interface. These sensors were not operational in 1987 and thus analyses and summaries were only performed on the 1985, 1986, 1988, and 1989 measurements.

Site Comparisons: Average air temperature (30cm) was 1.0 ^{o}C warmer at the control than at the antenna hardwood stand for the four years of measurements (Table 1.16). ANOVA tests showed significant differences between the sites (p=0.039). Differences in temperature (1.0^{o}C) between sites at 30cm above the ground were similar in magnitude to site differences in average air temperature at 2 m above the ground. Average air temperature above the ground 30 cm at the antenna and control sites were also within 0.1^{o}C of the average air temperatures at 2 m above the ground for each of the two sites.

Annual Comparisons: Average air temperature (30cm) in 1988 was 1.0^{o}C , 0.4^{o}C, and 0.7^{o}C warmer than in 1985, 1986, and 1989 respectively. However, no significant differences (p=0.310) were found among years in the analysis. Similar differences in air temperature among years were found to be significantly different for the air temperature sensors placed at 2 m above the ground. The greater sensitivity of ANOVA tests for air temperature 2m above the ground are a result of the greater number of plots and thus sensors involved in the measurements.

Site by Year Interactions: Differences between the air temperature at the sites were greater in 1988 (1.3^{o}C) than in the other three years. However no significant site by year interactions were found in this year's analysis (p=0.875).

Summary: Given the results of the analyses for air temperature at 30cm, we can not conclude the ELF antenna operation has affected this ambient variable. Differences in air temperature exist between the sites at this height above the ground, but these differences have remained stable over the duration of the study and site by year interactions were not significant.

Table 1.16 Comparison of air temperature 30cm above the ground at the control and antenna hardwood stands during 1985, 1986, 1988, and 1989

Average Daily Air Temperature 30cm (^{o}C)

	1985	**1986**	**1988**	**1989**	$\bar{X}$ [1]
Control	12.2	12.7	13.4	12.8	12.8 a
Antenna	11.5	12.0	12.1	11.7	11.9 b
$\bar{X}$	11.8 a	12.4 a	12.8 a	12.3 a	

[1] Site or year comparison with the same letter are not significantly different at (p=.05).

Summary

A large number of climatic factors have been found to vary significantly among sites and/or years (Table 1.17-1.18). Air temperature (2m), soil moisture content at 5 cm and 10 cm depths, soil moisture content (10 cm), water potential at 10 cm, and relative humidity are climatic variables which have been found to differ among the control and tests sites. Air and soil temperature, soil moisture and soil moisture potential, and precipitation change annually at the sites. Any of these climatic variables which differ among sites or years would be good candidates for modeling efforts or covariate analysis in the other elements of the project. However, before these climate variables are included in any final analyses, it must be shown that they are not correlated to ELF antenna operation.

We expect that any changes in a climatic variable as a result of ELF antenna operation would correspond to changes of the ecology at the test sites. To detect and quantify any changes in the climate at the test sites, comparisons of the climatic relationships between the control and test sites over the duration of the project are made. Changes in the relationships of the climate between the control and test sites would indicate possible ELF field effects on the ecology of the test sites. These changes are expressed in our statistical design through significant site by year and site

Table 1.17 Significant differences for control vs ground site comparisons

FACTOR

Variable	Site	Year	Site by Year
Air Temp. (2m)	*[1]	*	*
Soil Temp. (5cm)	-	*	-
Soil Temp. (10cm)	-	*	-
Soil Moist. (5cm)	*	*	-
Soil Wat. Pot. (5cm)	-	-	-
Soil Moist. (10cm)	-	*	-
Soil Wat. Pot. (10cm)	-	-	-
Relative. Humidity.	*	*	*
Precipitation.	-	*	-

[1] Factors denoted by * p<=.05.

Factors denoted by - p>.05

Table 1.18 Significant differences for the control vs antenna comparisons

FACTORS

Variable	Site	Year	Site by Year	Site by Stand Type	Site by Stand Type by Year
Air Temp. (2m)	*[1]	*	-	-	-
Soil Temp.(5cm)	-	*	-	-	-
Soil Temp.(10cm)	-	*	-	-	-
Soil Moist.(5cm)	*	*	*	*	-
Soil Wat. Pot.(5cm)	*	*	*	*	-
Soil Moist.(10cm)	*	*	-	-	-
Soil Wat. Pot..(10cm)	-	*	-	-	-
PAR	*	-	-		
Air Temp.(30cm)	-	-	-		
Rel. Hum.	*	*	-		
Precipitation	-	*	-		

[1] Factors denoted by * p<=.05

Factors denoted by - p>.05

by stand type by year interactions. To date air temperature (2m), soil moisture (5 cm), soil water potential (5 cm), and relative humidity have shown significant site by year interactions for the control vs ground comparisons and/or the control vs antenna comparison. To date no site by stand by year interactions have been significant (Table 1.17-1.18).

Significant site by year air temperature (2 m) interactions have been shown to be related to the productivity of the red pine at the control and test sites. Thus at least for this climatic variable potential effects of ELF electromagnetic fields on air temperature cannot be addressed until the effects of these fields on the productivity of red pine have been quantified. At this time the significant interactions for soil moisture (5 cm) soil water potential (5 cm), and relative humidity do not appear to be related to ELF antenna operation or changes in vegetation productivity among the sites.

Another approach used this year to quantify the relationships between ELF antenna operation and ambient measurements was to determine correlation coefficients between 76 hz field strengths and climatic variables. Significant correlations between these two factors would suggest that either ELF antenna operation has affected a given ambient variable or that an incidental relationship exist between a specific climatic factor and antenna operation. Table 1.19 presents the initial results from this approach. Ambient measurements used for the correlations were plot or site averages for each year during 1985-1988. Field strengths were determined by integrating the field equations from EW leg operation given in Appendix A over the entire plot. The fields from EW leg equations were chosen due to the stronger fields associated EW leg operation.

Longitudinal fields appeared to be more consistently correlated to climatic factors than were the magnetic and transverse fields. Longitudinal fields were more highly correlated with soil moisture and temperature than ambient variables measured in the air. These fields travel through the soil and are affected themselves by soil conditions. Significant correlations between soil variables and longitudinal field strengths may be due to the effect of the soil conditions on the fields themselves.

All three types of field strengths were negatively correlated to global solar radiation. Correlation coefficients for this variable and the three field measurements were between -.906 and -.934. The global solar radiation sensor is located 4 m above the soil surface at the ground site and could not be affected by any possible changes in vegetation induced by ELF fields. Thus the high correlation between global solar radiation and field strengths suggest that these two variables are confounded for the short time period examined.

Progress to date on this specific approach to quantifying the relationship between antenna operation and ambient measurements are limited. Future work will be done to more

Table 1.19. Correlation coefficients and significance levels (-.+,*, or **) associated with annual ambient variables and transverse, longitudinal, and magnetic EW leg antenna operation 76 hz field strengths (1985-1988).

	Transverse	Longitudinal	Magnetic
Air Temperature 2 m	-.100[1] -	-.114 -	-.080 -
Soil Temperature 5 cm	.140 -	.191 -	.150 -
Soil Moisture 5 cm	.132 -	.223 +	.126 -
Soil Temperature 10 cm	.187 -	.276 +	.195 -
Soil Moisture 10 cm	.186 -	.277 *	.178 -
Average Weekly Precipitation	-.007 -	.035 -	.014 -
Global Solar Radiation	-.934 +	-.906 +	-.925 +
Relative Humidity	.432 -	.400 -	.502 -
Solar Radiation Par	.608 -	.554 -	.595 -
Air Temperature 30 cm	-.034 -	-.178 -	-.186 -

1/- .10<p
 + .10≥p>.05
 * .05≥p>.01
 ** .01≥p

precisely determine if the relationships indicated in Table 1.19 are valid.

Nutrient Monitoring

Soil Nutrients

Tree productivity analysis completed during the past years have indicated that soil nutrients are valuable covariates in explaining site and year differences (see Element 2). In addition, analysis of northern red oak foliar nutrients and litter production have also included soil nutrient information. Thus the objective of the soil nutrient study is to document spatial and temporal variability of soil nutrients within the study area and determine if soil nutrients are independent of ELF field exposure, thereby determining the suitability of soil nutrients for inclusion in covariate analysis and modeling.

Sampling and Data Collection

Soil nutrient samples are collected monthly during the growing season. During the 1988 and 1987 growing season sampling began in May and concluded in October at the ground, antenna and control sites. In 1986, sampling began in June and concluded in September. However, in 1985 the hardwoods were sampled monthly, while the plantations were sampled only once in July. After initial success in using soil nutrients in the hardwood growth models, it was decided that sampling in the plantations would also be conducted monthly in successive years to provide soil nutrient data for the red pine growth analysis. Twenty randomly selected samples per plot were collected using a push probe inserted to a depth of 15 cm into the mineral soil. Samples were then composited to 5 per plot, dried in a convection oven at 60 degrees Celsius, and analyzed for Kjeldahl N, total P, and exchangeable Ca, Mg, and K.

Progress

Average monthly nutrient content values were generally greater in the hardwood stands at the control than at the antenna site for nearly all sampling dates in 1985-88 with the possible exception of nitrogen which seems to show more variability (Table 4, Appendix B). In addition, the 1985 Ca, Mg, K, and N values are generally higher than the following years for the hardwood stands (Figures 1-5, Appendix B). Nutrient data collected in 1985 is consistently higher than following years which introduces additional "noise" or variability. This is only a problem with the hardwood nutrient data since the plantations were not sampled monthly during 1985. There is a slight decline in all soil nutrients after 1985 with following years generally not being significantly different.

Hardwood Stands

Analysis of variance was conducted to test differences in soil nutrient content (Kg/ha) for site, year, and month for the hardwood stands (Table 1.20). Results varied depending upon the nutrient and factor tested but in general, significance levels were higher for sites than for years.

Table 1.20. Significance levels from the analysis of soil nutrient content, 1985-1988.

PLANTATIONS[a]

	Ca	**Mg**	**K**	**P**[b]	**N**
Site	.050	.110	.069	.092	.984
Year	.643	.002	.005	.045	.005
Site by year	.082	.220	.115	.528	.248
Month	.000	.072	.000	.012	.000
Month by site	.163	.764	.011	.016	.000
Month by site by year	.016	.075	.670	.010	.000

HARDWOODS[c]

	Ca	**Mg**	**K**	**P**[b]	**N**
Site	.023	.024	.001	.136	.628
Year	.000	.000	.000	.069	.000
Site by year	.025	.485	.284	.208	.022
Month	.001	.713	.000	.138	.000
Month by site	.108	.176	.471	.049	.000
Month by site by year	.002	.165	.359	.012	.000

[a] Plantations were sampled in July only in 1985, therefore analysis was conducted on June through September 1986-88 data.

[b] ANOVA for P was conducted on 1986 through 1988 data only due to differences in laboratory methods between 1985 and following years.

[c] ANOVA for hardwood stands was conducted on the months of June through September 1985-1988.

Potassium was used as a covariate in the hardwood productivity studies and has been the most important soil nutrient in terms of explaining growth differences between sites and years. Significant differences (p=0.05) were found for potassium and calcium for site, year, and month (Table 1.20).

Annual Comparisons: ANOVA tests showed that all nutrients were significantly different among years except P (Table 1.20). The nitrogen content has declined during the four year study (Table 1.21). Future work will address the explanation of such patterns. Phosphorus, which could only be compared for 1986, 1987, and 1988 showed no significant change. Ca, N and K exhibited the greatest contents during the first year (1985) of the study revealing the additional variability that this year introduces. The nutrient values following 1985 show that there is no significant change or only slight change which could be explained by variability among sites and years or sampling error. There is no significant differences from 1986 through 1988 for Ca, Mg, and K showing there has not been a change in these soil nutrients prior to or during testing of the ELF antenna.

Table 1.21 Soil means (Kg/ha) by year for hardwoods (85-88), and plantations (86-88).

HARDWOODS

			Nutrient		
Year	**Ca**	**Mg**	**K**	**P**	**N**
1985	590.11^{c}	76.09^{f}	76.00^{h}	-	1281.49^{l}
1986	373.49^{b}	79.20^{f}	60.23^{g}	659.79^{i}	1185.04^{k}
1987	317.85^{a}	55.78^{d}	62.45^{g}	673.14^{i}	1190.62^{k}
1988	356.30^{ab}	65.58^{e}	64.91^{g}	636.32^{i}	1078.40^{j}

PLANTATIONS

			Nutrient		
Year	**Ca**	**Mg**	**K**	**P**	**N**
1986	454.79^{a}	63.28^{c}	61.02^{d}	632.42^{f}	1113.46^{h}
1987	458.78^{a}	57.86^{bc}	63.39^{d}	619.57^{f}	1088.41^{h}
1988	446.42^{a}	55.46^{b}	64.58^{d}	575.71^{e}	990.79^{g}

Values for a given nutrient with the same letter are not significantly different at p=.05.

Site by Year Interactions: Comparisons between the control and the antenna showed that nutrient contents at both sites followed the same basic trends (Table 1.22, Figures 1-5 appendix B). Nitrogen and calcium were the only nutrients that exhibited a significant difference in site by year for the four year study (Table 1.20). The relationship between sites for Mg K and P remains the same over time indicating no change in soil nutrients during the antenna test period. The plantations show no significant differences for site by year for Mg, K, and P. Nitrogen at both sites exhibit an overall decrease from 1985 to 1988 but the control shows a slight increase in 1987 (Table 1.22). Further research will investigate the changes in site differences over time. Phosphorus has been stable and has not significantly changed over time. Calcium and potassium have been very stable since 1986 with the higher values occurring at the control. Both elements are significantly greater in 1985 but have not significantly changed since 1986. Magnesium at the antenna has not significantly changed from initiation of the study. There was a slight decrease in Mg at the control. The soil nutrients at the control have been greater than soil nutrients at the antenna in most cases.

Red Pine Plantations

July was the only month in 1985 in which sampling was conducted on the red pine plantations. As a result, only soil nutrient data from 1986, 1987, and 1988 were used in the analysis of variance. Significant site differences ($p=0.05$) were found for calcium only, and significant year differences exist for all nutrients except calcium (Table 1.20). Significant differences exist between months for all nutrients except Mg and P. The plantations exhibit trends similar to the hardwood stands (Figures 1-5, Appendix B).

Annual comparisons: Calcium and potassium showed no significant differences among years. Magnesium, phosphorus, and nitrogen have generally decreased slightly during the length of the study (Table 1.21).

Site by year interaction: There were no significant differences in site by year interactions for the plantations (Table 1.20). This indicates that there is no significant difference between test sites exposed to electromagnetic magnetic fields and the control over time, thus there is no evidence to indicate that ELF affected the nutrient content within the plantations.

Future work will focus on determining the effects of nutrient deposition from precipitation, nutrient removal by vegetation uptake and leaching, and other climatic factors on spatial and temporal variability in soil nutrient levels. These factors may be covariates explaining monthly differences in soil nutrients.

Table 1.22. Soil nutrient means (Kg/ha) by site and year for the hardwood stands.

Ca

Site	1985	1986	1987	1988
Control	675.58^{d}	377.47^{b}	373.28^{b}	364.20^{b}
Antenna	463.97^{c}	247.49^{a}	186.28^{a}	230.17^{a}

Mg

Site	1985	1986	1987	1988
Control	83.89^{d}	92.39^{d}	56.49^{bc}	68.05^{c}
Antenna	60.32^{bc}	48.00^{ab}	36.74^{a}	41.88^{ab}

K

Site	1985	1986	1987	1988
Control	80.66^{c}	53.24^{ab}	54.74^{ab}	53.08^{ab}
Antenna	60.41^{b}	43.28^{a}	43.66^{a}	46.55^{a}

P

Site	1985	1986	1987	1988
Control	-	721.37^{c}	724.59^{c}	663.23^{bc}
Antenna	-	525.20^{a}	608.44^{abc}	541.51^{ab}

N

Site	1985	1986	1987	1988
Control	1262.20^{d}	1000.72^{b}	1092.97^{bc}	866.40^{a}
Antenna	1190.20^{cd}	1086.72^{bc}	1083.97^{bc}	953.02^{ab}

Values for a given nutrient with the same letter are not significantly different at p=.05.

Element 2. Tree Productivity

Tree growth is sensitive to a variety of environmental disturbances. In order to detect any changes in growth due to treatment, accurate tree measurements are essential. The most widely accepted tree growth measurements are diameter at breast height outside bark (dbh) and height. Of these two growth variables, height is the more difficult to measure on mature trees. The installation of permanent dendrometer bands on the stem of a tree allows measurement of minute changes (0.008 cm) in diameter over a short time interval (Husch *et al.* 1982). Two additional advantages of using dbh as a measurement of tree growth are the responsiveness of cambial activity to environmental effects (Smith 1986) and the strong correlation between dbh and total biomass of the tree (Crow 1978). Consequently, measurement of diameter increment is the primary response variable for assessing the effects of ELF fields on hardwood stand growth. Tree height was used for initial stand characterization.

While dbh and height measurements can provide information on present stand production and a means to predict future productivity, the capacity of a stand to continue producing is also dependent on stand structure (the distribution of trees by diameter classes). Stand structure changes from year to year due to natural growth, reproduction, and mortality. Any environmental disturbance could produce an effect on these factors. Therefore, to achieve a complete picture of possible ELF field effects on tree and stand production, dbh, height, ingrowth, and mortality are being measured in order to distinguish natural changes from those caused by site disturbances.

In addition to tree productivity in hardwood stands, regeneration studies involving planted red pine are being conducted on the ground, antenna, and control sites. These studies were initiated in response to a need for a larger number of conifers in the ectomycorrhizal studies (Element 6) as well as to address the Michigan DNR concerns about forest regeneration. Since young trees often exhibit rapid growth rates compared to older trees, possible ELF field effects may be more easily detected on seedlings rather than on older trees. In the red pine seedlings, both diameter and height increment are response variables for assessing any possible effects due to ELF fields. Again, as in the case of trees in the hardwood stands, diameter, height, and mortality are being measured.

Hardwoods

Diameter increment is the primary response variable for assessing the effects of ELF fields on the hardwood stands located on the antenna and control sites. Permanently installed dendrometer bands allow continual measurement of incremental growth on each tree in the stand. This information provides a

view of both the total growth in an entire growing season and the rate or distribution of diameter growth over the growing season.

Hardwood stands on both study sites are classified in the Acer-Quercus-Vaccinium habitat type (Coffman *et al.* 1983). Those species common to both sites and included in the analysis are northern red oak (*Quercus rubra*), paper birch (*Betula papyrifera*), bigtooth aspen (*Populus grandidentata*), quaking aspen (*Populus tremuloides*), and red maple (*Acer rubrum*). A summary of stand information for both sites can be found in Table 2.1; the change in average dbh on the study sites for each year since 1984 is given in Table 2.2.

Each analysis will eventually test the overall null hypothesis:

H_0: There is no difference in the magnitude or the pattern of seasonal diameter growth before and after the ELF antenna becomes operational.

This hypothesis is addressed through testing of differences between the control and the antenna sites and testing between post-operational years and previous years. The system operated at low levels throughout the growing season during 1987 (15 amps) and 1988 (75 amps) with full power operation (150 amps) during 1989. Whenever possible, differences between sites and between 1987, 1988, 1989 and previous years are examined. Tests concerning the rate or the distribution of diameter growth are made using the diameter growth model discussed later in this section. Tests in previous years (Mroz *et al.* 1988) have shown that there are no significant differences in the parameters of the diameter growth model between years or across sites. Comparisons of post-operational years with previous years are in part made by examining residuals of individual tree diameter growth over different years and sites. Differences in the magnitude or amount of seasonal diameter growth are examined through the split plot analysis of covariance. The analysis of covariance table used in this study is found in Table 2.3. Since monthly soil nutrient concentrations are a critical covariate, the analysis of covariance reported here is performed on data through 1988. An analysis including the 1989 data will be performed following completion of laboratory analysis of the soil samples.

Sampling and Data Collection

To monitor diameter growth on both sites, permanent dendrometer bands were installed in 1984 on all trees greater than or equal to 10 cm dbh. Due to vandalism, 175 new bands were installed on the control site in 1985. On the antenna site the number of study trees was reduced from 209 in 1984 to 197 in 1985 due to a few band failures and a small vandalism incident unrelated to that on the control site. The death of one bigtooth aspen on the control site reduced that sample to 274 trees in 1985. At the start of the 1987 growing season, the trees which

Table 2.1. Summary of hardwood stand information for the antenna and control sites at the beginning of the 1989 growing season.

Species	Average DBH (cm)[b]	Basal Area Per Hectare (m^2/ha)	Number Bands in 86	Number Bands in 89[c]	Number of Stems per Hectare	Site Index	Age (yrs)
Antenna							
Northern Red Oak	24.11	8.05	44	49	156	68	50
Paper Birch	20.83	0.93	8	8	25	66	58
Aspen[a]	26.40	2.69	15	15	48	68	53
Red Maple	15.36	9.19	129	148	470	56	45
Control							
Northern Red Oak	21.42	21.73	174	177	556	72	55
Paper Birch	17.27	3.09	40	39	127	60	57
Aspen	23.51	6.10	44	43	137	65	58
Red Maple	12.73	1.01	15	22	70	58	48

a/The two aspen species are combined.

b/Average DBH includes ingrowth trees for 1987 but not trees which died in 1988.

c/Includes trees which grew to larger than 10.0 cm dbh since 1985 which were banded in 1987 but not trees which died in 1988.

Table 2.2. Average dbh (cm) by species and site at the beginning of each year of this study.[a/]

	1984	1985[b/]	1986	1987	1988	1989	1990
Antenna							
Northern Red Oak	22.18	22.45	22.69	23.09	23.36	23.76	23.99
Paper Birch	20.02	20.22	20.42	20.56	20.70	20.83	20.93
Aspen[c/]	24.59	25.01	25.37	25.67	25.93	26.20	26.49
Red Maple	14.87	15.09	15.23	15.33	15.44	15.89	15.98
Control							
Northern Red Oak	20.45	20.62	20.82	20.94	21.12	21.58	21.76
Paper Birch	16.12	16.23	16.30	16.36	16.41	17.21	17.24
Aspen	22.21	22.55	22.82	23.03	23.18	23.47	23.61
Red Maple	11.37	11.64	11.85	12.01	12.17	12.28	12.40

a/ Only trees banded prior to 1987 are represented here.
b/ Values given for the beginning of the growing season were calculated by adding all previous years growth to diameter taken in 1984.
c/ The two aspen species are combined.

Table 2.3. ANOVA table used for analysis of diameter growth by species.

Source of Variation					
Covariate	Group (A)	# group A covariates	SSC	MSC	MSC/MSE(S)
Site		1	SSS	MSS	MSS/MSE(S)
Error(S)		# trees-2-#covariates	SSE(S)	MSE(S)	
Years		# years-1	SSY	MSY	MSY/MSE(SY)
Site x Years		(1)(#years-1)	SSSY	MSSY	MSSY/MSE(SY)
Covariate	Group (B)	# group B covariates	SSCY	MSCY	MSCY/MSE(SY)
Error(SY)		(#trees-2-#covariates)(#yrs-1)	SSE(SY)	MSE(SY)	

Group A covariates differ by site but not by year, such as soil characteristics.
Group B covariates change from year to year, such as annual rainfall.

had band failures in 1985 on the antenna site, as well as all trees which had become larger than 10 cm in dbh since 1984, were banded on both sites (Table 2.1). In 1988, there were three trees on the control site (two paper birch and one bigtooth aspen) which died. This mortality in 1988 occurred on trees which had not grown appreciably since 1984, indicating that they were not very vigorous, and they probably succumbed to climatic stress during the 1988 growing season. In 1989, additional trees which had grown to exceed 10 cm dbh were banded giving a total of 220 trees on the antenna site and 281 trees on the control site (Table 2.1).

Bands were read to the nearest 0.01 inches of circumference at both study sites beginning on April 19 in an attempt to insure monitoring of diameter growht initiation. Weekly readings continued until October 11 when growth had slowed considerably and over 50 percent of leaf fall had taken place. This provided a total of 25 measurements in 1989.

Progress

Growth Analysis

Magnitudes and rates of diameter increment were examined for each species. Analysis of tree diameter is approached in two ways. The split plot analysis of covariance is used to determine if there is any change in the magnitude of average yearly diameter growth which may be due to ELF fields. Secondly, regression models were developed in past years (Mroz *et al.* 1988) to further quantify the relationships between tree, site, and climatic variables and tree diameter growth. These models are used to test for changes in both seasonal growth pattern within a year and relationships affecting total annual growth due to ELF fields. Examination of the individual tree diameter growth residuals is conducted to determine if there have been changes in the effects of tree, site, or climatic variables on individual tree diameter growth and to examine the effects of the level of ELF field exposure on diameter growth. The modeling analyses use information for trees banded since 1985. The split plot analysis of covariance only utilizes growth information on trees which have been banded for the entire study period.

Analysis of Total Seasonal Diameter Growth

At present, six years (1984 through 1989) of diameter increment data have been collected from trees on the study sites. In 1984, first incremental growth was not collected until early June due to a relocation of the control site. Because of this, total diameter increment in 1984 is not derived from dendrometer band data, but from spring and fall diameter tape measurements of individual trees. Also, due to installation and calibration of the ambient monitoring equipment, the climatic variables are not

completely available for 1984. For these reasons, the 1984 diameter growth measurements were not included in the analysis of covariance. Monthly soil nutrient concentration proved to be an important covariate for explaining both site and year differences in diameter growth. These data are not yet available for the 1989 growing season; the tree growth information from 1989 will not be incorporated into these analyses until a complete set of covariates is available. Table 2.4 presents the total annual diameter growth by species for each of the six growing seasons, even thoough data from 1984 and 1989 are not included in the following analyses.

Results of an intensive variable screening procedure to select covariates to include in the analysis of covariance for each species have been reported previously (Mroz *et al.* 1988). There have been no attempts to refine the set of covariates for each species this year. Since antenna activity has increased, attempts to redefine covariates using information from later years could be confounded with possible ELF field effects on diameter growth. The covariates used are total air temperature degree days through May for red maple and through September for the other three species, July soil potassium concentration for all four species, water retention capacity from 5 to 10 cm for red maple, and water retention capacity from 10 to 30 cm for paper birch.

An initial analysis of variance, without covariates, was performed for individual tree annual diameter growth for each species. In all four species, there were significant ($p<0.05$) differences indicated in individual tree diameter growth rates and among the study years (Table 2.5). For red maple, there was also a significant interaction between site and year. As indicated in previous years, a logarithmic transformation was applied to the northern red oak and red maple data prior to the analyses. An analysis of covariance using the covariates listed above indicated that there were no differences ($p=0.05$) in individual tree diameter growth between sites for any of the four species, there were differences ($p<0.05$) between years indicated for northern red oak but not the other species, and there were no significant ($p=0.05$) site and year interactions for any species.

To confirm the validity of the analysis of covariance, the correlations between average plot EM field exposure level and the covariates were calculated. One of the critical assumptions in an analysis of covariance is that the covariates are independent (uncorrelated) with the treatments, in this case the EM field exposure levels. Violation of this assumption implies that the effect of the fields is confounded with the covariates and the interpretation of the results becomes extremely difficult.

In this study, there was a significant positive correlation ($p<0.05$) between longitudinal field intensities and the degree day covariates at the control site. There were also significant correlations ($p<0.05$) between all three fields and the degree day covariates at the antenna site ($r=0.87$, 0.69, and 0.72 between the total seasonal air temperature degree days and the tangential, longitudinal, and magnetic fields, respectively, and $r=0.80$, 0.93, and 0.91 between the growing degree days in April

Table 2.4. **Average seasonal diameter growth (cm) for tree species on each site for the 1984, 1985, 1986, 1987, 1988 and 1989 growing seasons.[a]**

	Sample Size	1984	1985	1986	1987	1988	1989
		cm					
Northern Red Oak							
Antenna	44	0.2778	0.2389	0.1991	0.2710	0.2354	0.2256
Control	174	0.1707	0.2030	0.1508	0.1823	0.1595	0.1773
Paper Birch							
Antenna	8	0.2000	0.2038	0.1500	0.1304	0.1132	0.0990
Control	38	0.1050	0.0765	0.0652	0.0406	0.0419	0.0345
Aspen							
Antenna	15	0.4133	0.3653	0.2993	0.2355	0.2576	0.2877
Control	43	0.3386	0.2643	0.2164	0.1529	0.1713	0.1415
Red Maple							
Antenna	129	0.2163	0.1374	0.1017	0.1130	0.0830	0.0899
Control	16	0.2667	0.2040	0.1533	0.1768	0.0690	0.1152

[A]Only trees banded prior to 1987 are represented here.

Table 2.5. Significance levels[a] for the analyses of variance and covariance of individual tree diameter growth.

Species	Source of Variation Site	Year	Site*Year Interaction
Analysis of Variance (No Covariates)			
Northern Red Oak	.000	.000	.789
Paper Birch	.001	.020	.756
Aspen	.000	.000	.730
Red Maple	.000	.000	.030
Analysis of Covariance			
Northern Red Oak[b]	.344	.006	.225
Paper Birch	.189	.612	.977
Aspen	.605	.952	.750
Red Maple	.385	.144	.121

[a] A significance level less that 0.05 indicates a significant difference at p=0.05.

[b] For northern red oak and red maple, a logarithmic transformation was performed on individual tree diameter growth prior to analysis.

and May and the tangential, longitudinal, and magnetic fields, respectively). In addition, July soil potassium level was correlated ($r=-0.50$, $p<0.05$) with the tangential fields at the antenna site.

The fact that two variables are correlated does not imply a cause and effect relationship. In this case, the three years when the antenna was being tested at successively greater power just happened to be three years when temperature increased (Element 1). If there had been a longer period of time prior to antenna operation there might not have been any significant correlations between EM field levels and the covariates. Similarly, an extended study period after the antenna is operating at a relatively constant level would decrease the likelihood of significant correlations. In any case, at this time the covariates are significantly correlated with EM field exposure levels and the analysis of covariance of individual tree diameter growth should not be considered to be a reliable test of the effects of EM fields; the analyses of covariance do not suggest a significant effect due to EM fields but there could still be an effect which is masked by the correlations between the EM field exposure level and the covariates.

Diameter Growth Model

Many of the relationships between diameter growth and tree, site, and climatic variables can be expected to be nonlinear (Spurr and Barnes 1980, Kimmins 1987). These nonlinear relationships cannot be adequately accounted for in the analysis of covariance described above. In order to supplement the analysis of covariance, diameter growth models for each of the four species were developed (Mroz *et al.* 1988) to further account for the variability in growth between sites and over years. The growth model also provides an annual residual for each tree which can be examined to see if the diameter growth following antenna activation is diverging from patterns seen in previous years; no similar quantity is available by individual tree from the analysis of covariance. Since the seasonal pattern of diameter growth as well as total annual growth could be subject to ELF field effects, the weekly cumulative diameter growth (cm) was selected as the response variable.

Differences in diameter growth observed since 1985 include differences in the timing of growth between sites, differences in the timing of growth between species, and differences in the timing of growth between years (Mroz *et al.* 1986). Since the stand conditions have not changed drastically since 1985, these observed growth differences are largely due to differences between species, climatic differences between years, and physical differences between sites. These differences have largely been accounted in the diameter growth models (Mroz *et al.* 1988).

Cumulative diameter growth is broken into the component parts of total annual growth and the proportion of total growth completed by the date of observation. This simplifies the testing for significant effects of ELF fields on tree diameter

growth. Cumulative diameter growth to time t is therefore represented by:

$$CG_t = \text{(Total Annual Growth)(Proportion of Growth to Time t)}$$

This formulation allows the testing of ELF field effects on both the level of total annual growth (TAG) and the pattern of seasonal growth. In the model, total annual growth is further broken into the component parts of potential growth, the effect of intertree competition, and the effect of site physical, chemical, and climatic properties:

$$\text{TAG} = \text{(Potential Growth)(Intertree Competition)(Site Physical, Chemical, and Climatic Properties)}$$

The degree of intertree competition is dependent on the distances and sizes of neighboring trees. Since the current stand maps extend only to the plot boundaries, the competitors for trees near the boundaries could not be determined. For this reason, only trees in the center 15 m could be utilized for the analyses with the growth model. In 1989, an additional 10 m buffer zone was mapped around each plot to allow the utilization of more trees in the analysis of the 1989 data.

The possible effects of ELF fields on total annual diameter growth are investigated by examining the individual tree residuals (observed diameter growth minus the diameter growth predicted by the model) each year. If there is an effect from ELF fields on diameter growth, the residuals should increase or decrease, indicating a divergence from past patterns of growth. Any apparent increase or decrease in residuals can be further investigated by examining the correlations between the residuals and ELF field exposure variables for each site and year. Possible changes in seasonal diameter growth pattern can be examined by looking at the expected pattern of growth from the model and possible deviations from that pattern in the data.

Total Annual Diameter Growth

Differences between the predicted total seasonal diameter growth and the observed values were obtained by site and year for each species. If there is a change in the way a tree is responding to site or climatic conditions then the model will not perform as well. In other words, the differences between the observed and predicted diameter growth will increase if an additional factor is introduced which impacts tree growth. Average residual and studentized 95 percent confidence intervals for the average residual are given by site and year for northern red oak in Table 2.6, for paper birch in Table 2.7, for aspen in Table 2.8, and for red maple in Table 2.9.

For northern red oak, the 95% studentized confidence interval for the average residual overlaps zero in all years with the exception on the antenna site in 1987. The confidence intervals from the two sites overlapped each other and zero in

Table 2.6. **Performance of the combined diameter growth model by site and year for northern red oak.**

Site	Year	Number of Observations	Average Residual (cm)	Standard Error of Residuals (cm)	Studentized 95% Confidence Interval
Antenna	1986	20	0.0204	0.0251	-0.0321, 0.0776
	1987	22	0.0797	0.0323	-0.0125, 0.1469
	1988	23	0.0250	0.0202	-0.0169, 0.0669
Control	1986	61	-0.0069	0.0103	-0.0275, 0.0137
	1987	62	0.0135	0.0112	-0.0089, 0.0359
	1988	62	-0.0178	0.0113	-0.0414, 0.0048

Table 2.7. Performance of the combined diameter growth model by site and year for paper birch.

Site	Year	Number of Observations	Average Residual (cm)	Standard Error of Residuals (cm)	Studentized 95% Confidence Interval
Antenna	1986	3	0.0191	0.0241	-0.0846, 0.1228
	1987	3	-0.0053	0.0153	-0.0711, 0.0605
	1988	3	-0.0048	0.0207	-0.0939, 0.0843
Control	1986	10	0.0047	0.0162	-0.0319, 0.0413
	1987	10	0.0007	0.0086	-0.0188, 0.0202
	1988	10	0.0270	0.0208	-0.0200, 0,0740

Table 2.8. Performance of the combined diameter growth model by site and year for aspen.

Site	Year	Number of Observations	Average Residual (cm)	Standard Error of Residuals (cm)	Studentized 95% Confidence Interval
Antenna	1986	11	0.0282	0.0193	-0.0143, 0.0707
	1987	11	0.0599	0.0227	0.0099, 0.1099
	1988	10	0.1175	0.0175	0.0779, 0.1571
Control	1986	30	0.0533	0.0222	0.0079, 0.0987
	1987	29	0.0032	0.0133	-0.0240, 0.0304
	1988	28	0.0033	0.0184	-0.0048, 0.0411

Table 2.9. Performance of the combined diameter growth model by site and year for red maple.

Site	Year	Number of Observations	Average Residual (cm)	Standard Error of Residuals (cm)	Studentized 95% Confidence Interval
Antenna	1986	70	-0.0019	0.0059	-0.0136, 0.0098
	1987	80	0.0002	0.0064	-0.0125, 0.0129
	1988	84	-0.0771	0.0053	-0.0876, -0.0666
Control	1986	10	0.0307	0.0143	-0.0016, 0.0630
	1987	10	0.0095	0.0129	-0.0197, 0.0387
	1988	10	-0.0852	0.0243	-0.1402, -0.0302

1988, indicating that there was no apparent difference in the growth patterns between the two sites. The apparent difference noted in the 1987 data would appear to be an anomaly given the results of the comparisons using the 1988 data. There is no evidence that the ELF fields have impacted total annual northern red oak diameter growth on the study sites.

For paper birch, the 95% studentized confidence intervals overlap zero for all years and sites. The average annual diameter growth appears to be consistent for all sites and years, providing no evidence of an affect of the ELF fields on paper birch total annual diameter growth.

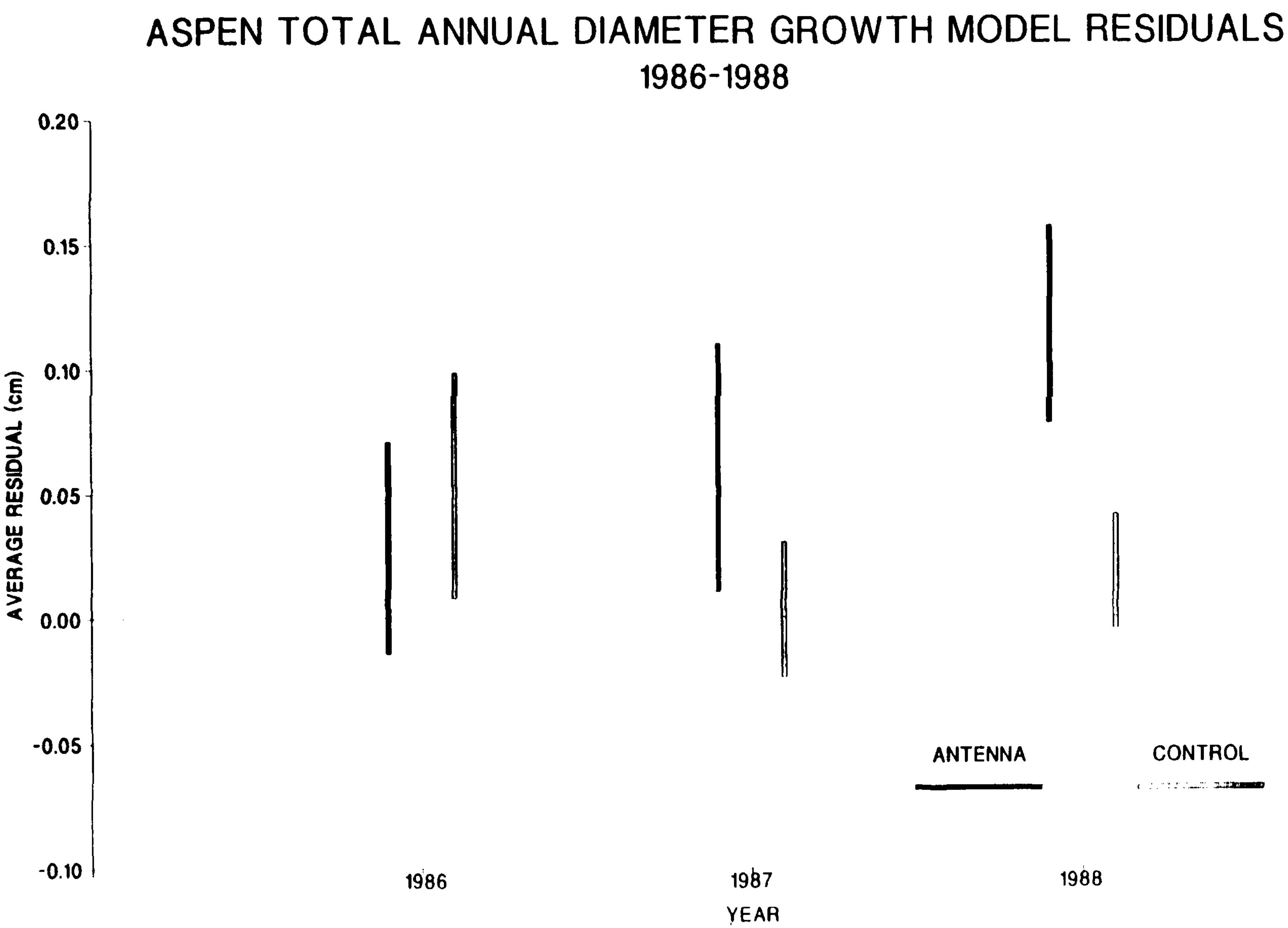
For red maple, the 95% studentized confidence intervals for the average residual overlapped zero for both the antenna and control site in 1986 and 1987. In 1988, the average residual for both sites was negative, indicating that growth was less than expected by the model. This pattern was true for both sites, indicating that whatever factor caused this reduction in growth was common to both sites. There is, therefore, no evidence to indicate that ELF fields played any role in this growth reduction since it also occurred on the control site. The temperature, moisture, and nutritional variables in the growth model did not account for this growth reduction. Work is currently being undertaken to try to explain these results.

For aspen, the 95% studentized confidence intervals overlapped zero at the control site in 1987 and 1988. In 1986, there was a slight positive residual indicating that the trees had grown faster than predicted by the model. In contrast, there has been a consistent pattern of increasing residuals over time at the antenna site (Figure 2.1). In 1986, the 95% studentized confidence interval overlapped zero, in 1987 it was slightly greater than zero, and in 1988 it was much greater than zero. As discussed below, there are several possible hypotheses that may explain this trend, but it is consistent with a positive effect of ELF fields on aspen total annual diameter growth.

One possible explanation for the increased annual diameter growth of aspen at the antenna site might be that the trees are showing a greater response to increased light from the opening of the antenna right of way. This does not seem to be the case because the aspen trees included in the analysis at the antenna site average 26.6 m from the edge with a standard deviation of 6.5 m. At the control site the average distance from the edge is 27.4 m with a standard deviation of 5.8 m. Clearly, there is no significant difference between sites in the distance to the edge of the right-of-way and, consequently, response of aspen to the opening is not a viable explanation for the increased growth at the antenna site.

Another possible explanation could be that the aspen at the antenna site is taking advantage of the reduced growth of red maple. As mentioned above, red maple growth was reduced at both the antenna and control sites and red maple does make up a greater proportion of the stand at the antenna site than the control. This seems unlikely, however, since aspen is extremely shade intolerant and would in all likelihood require some reduced competition for light to prompt a growth response. Red maple

Figure 2.1



ASPEN TOTAL ANNUAL DIAMETER GROWTH MODEL RESIDUALS
1986-1988
AVERAGE RESIDUAL (cm)
0.20
0.15
0.10
0.05
0.00
-0.05
-0.10
ANTENNA
CONTROL
1986
1987
1988
YEAR

foliar biomass in 1988 was 143 g/m^2 as compared to 147 g/m^2 and 142 g/m^2 in 1986 and 1987, respectively (Mroz *et al.* 1988). These differences are not significant, and there were no significant differences in total leaf biomass, between the antenna and control sites or between 1988 and previous years (Mroz *et al.* 1988). There does not, therefore, appear to be a reduced competitive environment for light in 1988.

For aspen to be taking advantage of reduced competition from red maple at the antenna site, the aspen would have to be responding to increased soil nutrient or moisture availability. There were no significant differences ($p>0.05$)in average soil moisture content (%) or soil water tension (-MPa) during the growing season at the antenna site between 1987 and 1988. There were also no significant differences ($p>0.05$) in levels of soil nitrogen, phosphorous, calcium, magnesium, or potassium between 1987 and 1988 at the antenna site. This implies that, even though red maple may be growing slower and therefore have less nutrient and moisture uptake, the availability of moisture and nutrients in the soil was not significantly increased. Aspen leaf biomass at the antenna site has been very variable with 46, 53, 48, and 59 g/m^2 being produced in 1985, 1986, 1987, and 1988, respectively (Mroz *et al.* 1988). These differences are not significant ($p>0.05$) but there is an increase in foliar biomass from 1987 to 1988 which is consistent with a response to better nutrition and increased moisture availability. Examples of mature aspen responding to increased moisture or nutrients without increased light availability could not be found in the literature. It is possible that a phenomenon concerning aspen response to site physical and chemical characteristics which has not been previously reported in the literature has occurred on the antenna but not the control site. It seems more likely, however, that the response of aspen to reduced competition for moisture and nutrients due to reduced red maple productivity is not a viable explanation for the increased total annual diameter growth of aspen at the antenna site.

Aspen was the only one of the four species which had a significant correlation ($p=0.05$) between the total annual diameter growth residuals and the average EM field strengths at the antenna site within years. The total annual growth model residual was negatively correlated ($p<.05$) with transverse field strength (V/m) in 1987 ($r=-0.639$) and 1988 ($r=-0.636$). In 1986, the correlation was -0.450 which was not significant ($p>0.05$). The interpolation of transverse field exposure levels is the least precise of the three field types (Appendix A). The correlation with magnetic flux (mG) was significant ($p<0.05$) in 1987 ($r=-0.702$) but not in 1986 ($r=-0.458$) or 1988 ($r=-0.504$) while the correlation with longitudinal field strength was not significant ($p>0.05$) in any year. There were no significant correlations between aspen diameter growth model residual and EM field strength at the control site for any year.

When combining the data and looking across all three years, there is no significant relationship ($p>0.05$) between the diameter growth model residual and average EM field strength for northern red oak or paper birch at the antenna site. For red

maple, there are significant negative correlations at both the antenna and the control sites which appear to be related to the reduced aspen growth observed on both sites in 1988. As discussed earlier, this growth reduction of red maple does not appear to be related to ELF fields. For aspen, there is a significant ($p<0.05$) positive correlation between diameter growth model residual and average longitudinal ($r=0.52$) and magnetic ($r=0.43$) field strength at the antenna site; at the control site there are no significant correlations between average diameter growth model residual and EM field strength.

These results imply that as the antenna power has increased, the aspen at the antenna site have increased their total annual diameter growth beyond what would be expected given the temperature, moisture, soil nutrient, and intertree competition levels present on the site. Within any year, however, trees further from the antenna, and therefore subject to lower field strengths, are showing a significantly greater residual than those closer to the antenna. The implications here are certainly not clear. However, the situation at the antenna site is different from the control site and alternative explanations, such as aspen release following clearing of the right-of-way or a response by aspen to greater soil moisture or nutrient availability do not seem to be viable explanations for the observed phenomena. At this point in time, the strengths of the EM fields at the antenna sites are significantly related to aspen growth patterns, but there is not sufficient evidence to claim that a cause and effect relationship exists.

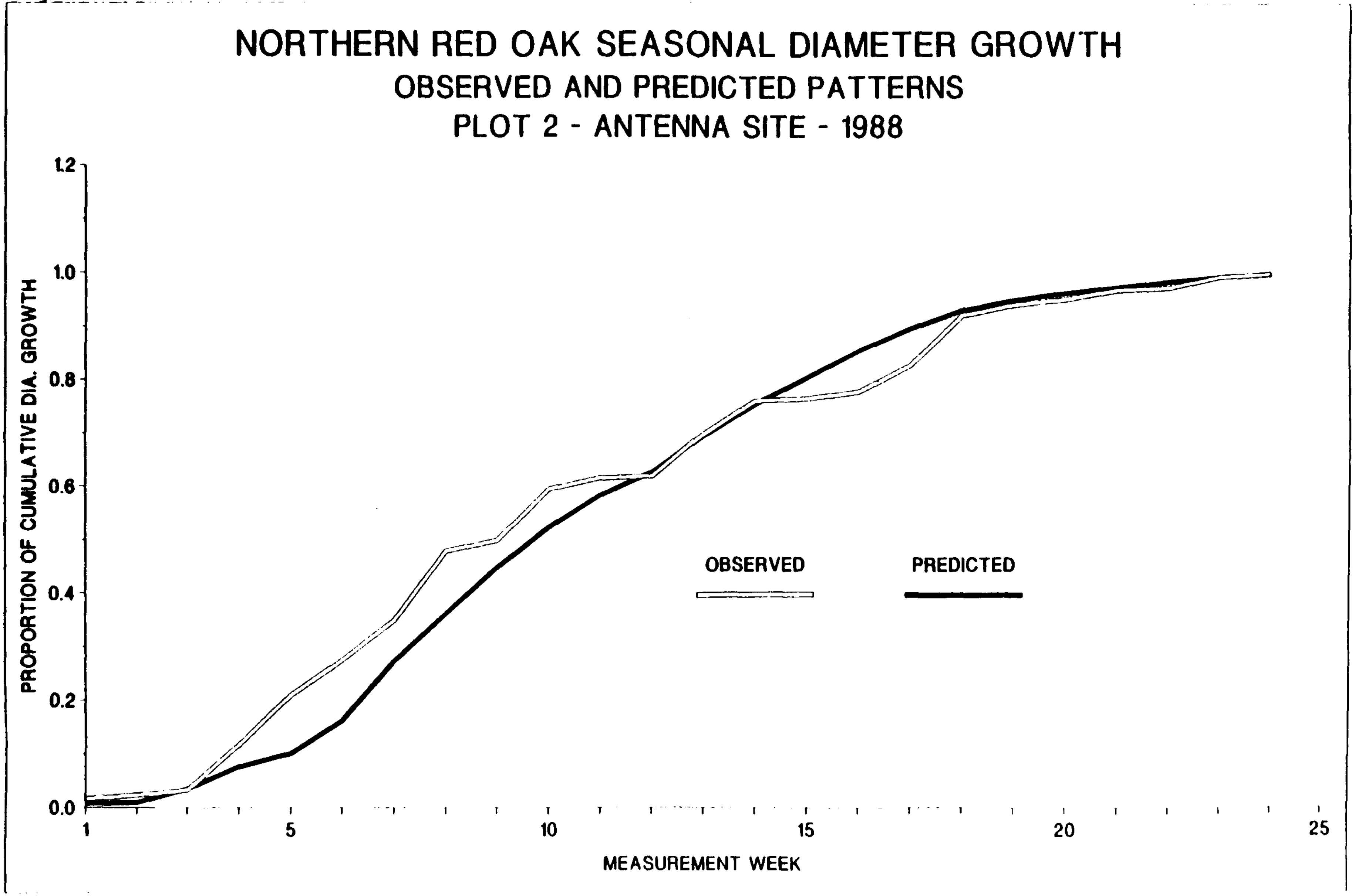
Seasonal Growth Pattern

Possible ELF field effects on seasonal diameter growth pattern are examined by using the Kolmogorov-Smirnov procedure to compare the distribution of seasonal growth predicted by the growth model (Mroz *et al.* 1988) to the observed distribution of seasonal growth from each plot each year. If an environmental factor which is not accounted for in the growth model is significantly impacting seasonal diameter growth, the observed growth pattern will differ from that predicted by the model. An illustration of the observed and predicted growth patterns is given for one species on one plot in one year in Figure 2.2.

For northern red oak, there are no significant differences ($p>0.05$) between the observed and predicted seasonal diameter growth patterns at either site in 1986, 1987, or 1988. This indicates that there is no significant ($p>0.05$) deviation from the seasonal diameter growth pattern predicted by the diameter growth model and, therefore, there is no evidence of an ELF field effect on the seasonal growth pattern of northern red oak.

For paper birch at the antenna site, there were no significant differences ($p=0.05$) between the observed and predicted seasonal diameter growth patterns for any plot in 1986, 1987, or 1988. At the control site, there were significant differences ($p<0.05$) between the observed and predicted seasonal diameter growth patterns on plot 3 in 1986, 1987, and 1988 and on

Figure 2.2


NORTHERN RED OAK SEASONAL DIAMETER GROWTH
OBSERVED AND PREDICTED PATTERNS
PLOT 2 - ANTENNA SITE - 1988
PROPORTION OF CUMULATIVE DIA. GROWTH
1.2
1.0
0.8
0.6
0.4
0.2
0.0
1
5
10
15
20
25
MEASUREMENT WEEK
OBSERVED
PREDICTED

plot 2 in 1987 and 1988. There were no significant differences on plot 1. The reasons for these differences at the control site are not perfectly clear but it is likely that they are due at least in part to the drier conditions at the control site than the antenna site (Mroz *et al.* 1988) and the fact that one of the significant covariates explaining differences in paper birch diameter growth between sites was soil moisture holding capacity (Mroz *et al.* 1988). In any case, there were no differences at the antenna site and the differences at the control site are not related to levels of ELF field exposure.

There were no significant ($p>0.05$) differences between the observed and predicted seasonal growth patterns for red maple on any plots at the control site in 1986 or 1987 but there was a difference ($p<0.05$) on one plot in 1988. At the antenna site, there was a difference ($p<0.05$) between the observed and predicted seasonal diameter growth patterns on one plot in 1986 and on a different plot in 1988; there were no significant ($p>0.05$) differences in 1987. The difference in 1986 appears to be an anomaly in the data since there were no differences for that plot in 1987 or 1988. The differences in 1988 are probably related to the reductions in total annual growth observed for red maple in 1988 compared to previous years. In any case, there was a difference on one plot on each of the control and antenna sites in 1988; these differences do not appear related to ELF fields.

There were no significant differences ($p>0.05$) between the observed and predicted seasonal growth patterns for aspen for any plots at the control site in 1987 or 1988 but there was a difference ($p<0.05$) on one plot at the control site in 1986. At the antenna site, there were no differences between observed and predicted seasonal diameter growth patterns in 1986 or 1987 but there was a difference ($p<0.05$) on one plot in 1988. The difference on the plot at the control site in 1986 was not repeated in 1987 or 1988. This plot only has three aspen trees on it and the difference can probably be attributed to the small sample size. The same can be said of the difference on the one plot at the antenna site in 1988. This plot only contains one banded aspen and, while it could possibly be related to the increases in total annual diameter growth at the antenna site, unless the difference between observed and predicted diameter growth pattern is repeated in the future and occurs on the other two plots at the antenna site, there is no real evidence of an effect of ELF fields on aspen seasonal diameter growth pattern.

Summary

1. There were no significant differences ($p>0.05$) in average total annual diameter growth for any of the four species indicated in the analysis of covariance. The covariates, particularly the degree day measurements, are significantly correlated ($p<0.05$) with ELF fields over the three years which confuses the interpretation of these results. At this point in time, because of the relationship between the covariates and the treatment (ELF field exposure), the results of the analyses of

covariance should not be considered alone in evaluating the effects of the ELF fields of diameter growth. As the study period lengthens, the correlations between the ELF field exposure levels and the covariates would be expected to decrease unless the covariates are directly affected by the fields.

2. The diameter growth model was developed to overcome many of the limitations of the analysis of covariance; by examining the residuals from the model, and determining if they increase or decrease with ELF field exposure, the effects of ELF fields can be more easily separated from the background variation due to climate, site, and stand conditions. In the analysis of the residuals, there was no indication that ELF fields were affecting the diameter growth of northern red oak or paper birch. Red maple showed a reduction in growth from previous years but this occurred on both the antenna and the control site and did not appear to be related to ELF field strengths. Aspen, on the other hand, showed increased growth on the antenna site which did not occur on the control site and which could not easily be explained by site or stand conditions. At this time, the evidence is consistent with a positive effect of increasing ELF fields on aspen diameter growth but there is not definitive evidence of a cause and effect relationship.

3. There were no differences in the observed and predicted seasonal diameter growth patterns for any of the four species which were related to ELF field exposure levels.

At this time, there is evidence which is consistent with there being a significant relationship between aspen diameter growth and ELF field exposure levels at the antenna site. There is no definitive proof that this relationship exists but the observed differences are not easily explained by existing knowledge of aspen physiological or ecological growth relationships. Such relationships are not apparent for the other three species and none of the four species show any evidence of alteration in seasonal diameter growth pattern due to ELf field exposure.

Red Pine

Seedling Growth

Since young trees experience rapid growth rates, possible effects of ELF electromagnetic fields on growth may be more easily detected on seedlings rather than on older more slowly growing individuals. Other justifications for investigating red pine seedlings are: 1) Michigan DNR concerns over effects on forest regeneration, 2) the lack of sufficient natural conifer regeneration on the study sites for mycorrhizal studies, and 3) the magnetic fields associated with the antenna ground rapidly decrease over a short distance. Thus, construction of the antenna ground through a red pine plantation allows the study trees to be closer to the electromagnetic source than any mature tree plots which require a buffer strip of trees along the right-of-way.

Total height (cm) and basal diameter (cm) increment on the red pine seedlings are the response variables for assessing possible ELF electromagnetic field effects. Measurements made weekly (on seedling height only) and seasonally (seedling height and diameter) allow examination of both the total growth in a growing season as well as the distribution of growth within the season. This study is conducted on the ground, antenna, and control sites. A summary of stand information for the three study sites can be found in Table 2.10. A summary of all average diameters and heights at each study site over the length of the study are found in Table 2.11.

The evaluation of red pine seedling growth is divided into two areas: 1) the determination of annual growth, vigor, and survival, and 2) the evaluation of seedling growth patterns as a function of time. The overall null hypotheses tested in this phase of the study are:

> H_O: There is no difference in the level of seasonal diameter growth of planted red pine seedlings before and after the ELF antenna becomes operational.

and

> H_O: There is no difference in the level or the pattern of seasonal height growth of planted red pine seedlings before and after the ELF antenna becomes operational.

As discussed earlier in the hardwood stand analyses, evaluation of possible ELF electromagnetic fields on height growth is approached in two forms: the level or amount of height growth in a growing season is analyzed through the analysis of covariance while the pattern of height growth within a growing season is described through a nonlinear height growth model. As mentioned earlier, the ELF system has operated at low levels throughout the 1987 (15 amps) and 1988 (75 amps) growing seasons. In late 1989 the system began operating at full power. Each of these analyses examines possible site differences as well as any existing differences between pre-operational and post-operational years. The analysis of covariance table used is the same as that found in the hardwood studies (Table 2.3). Development of a nonlinear height growth model from previous years data (Mroz et al. 1988) provides residuals from the model for individual seedling height growth. By examining the residuals, comparisons may then be made between pre- and post-operational years and any changes due to site or climatic variables can be evaluated. The level or amount of diameter growth in a growing season will only be analyzed through the analysis of covariance.

Table 2.10. Summary of red pine stand information for the ground, antenna, and control sites at the end of the 1989 growing season.

Site	Sample Size	Average DBH (cm)	Average Height (cm)	Average Bud Size (mm)
Ground	138	3.38	131.41	28.27
Antenna	158	3.88	146.32	30.47
Control	183	3.71	159.02	31.19

Table 2.11. Average diameter (cm) and height (cm) for each site at the end of each year of this study.

	Sample Size	Diameter (cm)	Height (cm)
Ground			
1984	300	0.450	17.18
1985	170	0.743	22.73
1986	147	1.280	37.33
1987	141	1.880	59.19
1988	137	2.427	90.22
1989	138	3.375	131.41
Antenna			
1984	300	0.441	16.80
1985	188	0.701	23.92
1986	184	1.262	40.34
1987	177	2.117	66.55
1988	164	2.794	100.77
1989	158	3.877	146.32
Control			
1984	300	0.459	18.96
1985	217	0.792	28.33
1986	211	1.355	50.50
1987	199	2.116	69.85
1988	192	2.706	116.69
1989	183	3.705	159.02

Sampling and Data Collection

Areas at the antenna, ground, and control sites were whole-tree harvested in June of 1984. These areas were immediately planted with 3-0 stock red pine seedlings at a 1 m by 1 m spacing. This density provided adequate numbers of seedlings for destructive sampling throughout the study period, allowed for natural mortality, and will leave a fully stocked stand when the study is completed. Following planting, 300 seedlings at each site were randomly selected and permanently marked for survival and growth studies. Additional details concerning the establishment of the red pine plantations can be found in past reports (Mroz et al. 1985, 1986).

Natural mortality following the first full growing season (1985) was 43 percent at the ground site, 37 percent at the antenna site, and 28 percent at the control site. This mortality was somewhat high due to the late planting date which resulted in planting shock as well as desiccation of seedlings during handling and planting. In addition, Mroz et al. (1988) observed that 61 percent of the apparently healthy seedlings that did not form terminal buds following planting died, which further indicates the inability of some seedlings to adapt to the planting site. Precipitation during 1985 was adequate for seedling establishment and competition around each seedling was minimal. It is unlikely that these environmental factors had a significant effect in causing this mortality. The mortality that occurred in 1985 was not evident in 1986, 1987, 1988, or 1989. Only a few seedlings died during the course of the last four growing seasons (Table 2.11).

Vegetative recovery following whole-tree harvesting in 1984 increased in 1986. This vegetation competed with the red pine seedlings for physical resources such as moisture, nutrients, and light. Vegetation control was necessary in 1986 to prevent the competing vegetation from affecting the unrestricted growth of the seedlings. In early June of 1986, competing vegetation was mechanically removed from each plantation plot using gas powered weed-eaters equipped with brush blades. This method was successful in releasing overtopped seedlings and essentially eliminating competition in 1986. Since then we have found sufficient carryover effect to suggest that it was not necessary to repeat weed control again, although woody stump sprouts and aspen suckers were removed in 1989.

For red pine growth analyses, each of the live permanently marked seedlings on each site was measured at the end of the growing seasons in 1984, 1985, 1986, 1987, and 1988, and 1989 and the following information recorded:

basal diameter (cm)
total height (cm)
terminal bud length (mm)
microsite
physical damage
presence of multiple leaders
number of neighboring seedlings

Information on microsite, physical damage, multiple leadered seedlings, and the number of neighboring seedlings was collected for possible use in explaining results of the growth analyses. Microsite described the physical environment in the immediate vicinity of the seedling such as rocky soil surface or proximity to a stump or skid trail. In 1988 this measurement also included whether the seedling was located in a frost pocket or not. This was based on a visual determination of the surrounding topography. Any physical damage to a seedling such as frost or animal damage was also recorded. Some seedlings possess two or more leaders, none of which expressed dominance over the others, and this situation was noted as well. In addition, beginning in 1987, the number of seedlings surviving in neighboring planting spacings was also recorded to aid in describing any future competition for light and moisture between neighboring seedlings. In 1989, the position and the elevation of each seedling has been mapped on a coordinate system and will be used in calculating amounts of exposure and analyzing effects of ELF fields. Competition affecting the seedlings will be measured early in the spring of 1990, prior to the initiation of the new growing season.

To further describe the growth of the red pine seedlings, a subsample of 100 seedlings per site was selected from the permanently marked seedlings for weekly height growth measurements. These weekly measurements were obtained in 1985, 1986, 1987, 1988, and 1989. Measurements began in mid-April while shoots are still dormant and continued until mid-July when shoot elongation was completed. Measurements (to the nearest 1 mm) were made from the meristematic tip or the tip of the new terminal bud to the center of the whorl of lateral branches.

Progress

Growth Analysis

The two response variables in this segment of the study are height and diameter increment of red pine seedlings. Differences in total seasonal height or diameter increment from site to site or from year to year are analysed through the analysis of covariance where tree, soil physical and chemical properties, and climatological data are used as covariates. The pattern of height growth in terms of the elongation of the leading shoot during the growing season is depicted through a growth model. This model has been developed to describe height increment only and will be used to provide an annual residual for each tree. The residual is examined to determine if current year shoot elongation changes from patterns observed in earlier growing seasons.

Total Annual Height and Diameter Growth

Covariate selection

Separate analyses of covariance examine any existing differences in either seasonal height or diameter increment among the three sites as well as from year to year. At this point there are five years of growth measurements available (1985, 1986, 1987, 1988, and 1989). Previous analyses have indicated the importance of soil nutrient concentrations as covariates to explain both site and yearly differences that occur in the height and diameter growth (Mroz et al. 1986). Therefore, until 1989 soil nutrient analyses are completed, all growth analyses discussed include data from 1985, 1986, 1987, and 1988 only. The average seasonal growth for each of these response variables on each site at the end of each growing season are found in Table 2.12.

Annual height growth

Earlier analyses (Mroz et al. 1988) have indicated that use of the previous year's site physical and chemical and climatic data explained more site and yearly variation than the current year's data when analyzing annual height growth. For this reason height growth occurring in 1986 , 1987, and 1988 coupled with 1985, 1986, and 1987 soil physical and chemical properties and climatic data are included in this particular analysis. The use of the previous year's soil physical and chemical properties and climatic data provides results that are consistent with the fact that red pine ia a species of deterministic growth. Height growth in any year is strongly related to the size of the terminal bud which was formed under the previous year's site physical, chemical and climatic conditions (Kozlowski et al. 1973).

Prior to analyses of covariance, an analysis of variance (no covariates included) was performed and highly significant differences in height growth were found among the three sites and among the three study years ($p<0.001$). There was also a significant interaction between the study sites and years ($p<0.001$) (see Table 2.13).

The covariates used from previous work (Mroz et al. 1988) were again examined in the analysis of covariance. These covariates included average maximum air temperature for the month of June, total Kjeldahl nitrogen in the soil during July, and water holding capacity from 10 t0 30 cm in the soil. One assumption in the analysis of covariance is that the covariates be independent of the treatment; in this case, each covariate selected should not be linearly correlated with the EM fields. Correlations were calculated across time between the selected covariates and average EM fields during the growing seasons. At

Table 2.12. Average seasonal diameter growth (cm) and height growth (cm) for each site for the 1985, 1986, 1987, and 1988 growing seasons.

	1985	1986	1987	1988
Diameter Growth (cm)				
Ground	0.27	0.53	0.60	0.54
Antenna	0.23	0.55	0.86	0.65
Control	0.32	0.57	0.76	0.61
Height Growth (cm)				
Ground	5.08	14.28	23.75	28.70
Antenna	6.61	16.06	26.96	33.53
Control	8.34	22.34	31.87	35.02

Table 2.13. Significance levels from the analysis of height growth (cm) and diameter growth (cm) with and without the use of covariates.

Factor	No Covariates	Covariates
Height Growth (cm)		
Site	0.0000	0.1111
Year	0.0000	0.0000
Site x Year	0.0000	0.0394
Diameter Growth (cm)		
Site	0.0000	0.2598
Year	0.0000	0.0771
Site x Year	0.0000	0.0000

A/A significance level smaller than 0.05 would indicate significance (p=0.05).

the ground and antenna sites maximum air temperature in the month of June was significantly correlated (p=0.05) with the transverse field (V/m) (r=.6289 and r=.8724, respectively), the longitudinal field (mV/m) (r=.6253 and r=.8862, respectively), and the magnetic flux (mG) (r=.6648 and r=.9073, respectively). Water holding capacity at 10 to 30 cm was also significantly correlated (r=.5072) with the longitudinal fields (mV/m) at the ground site. At the control site maximum air temperature in June was significantly correlated (p=0.05) with the longitudinal field (mV/m) (r=.8461). The significant linear correlations with maximum air temperature in June may be explained by the existing linear trend in the data. Maximum air temperature values in June have steadily increased from 1985 (averaging 16° C to 17° C across the three sites) to 1988 (averaging 23° C to 24° C across the three sites). This increase corresponds to the increasing field exposures as the antenna operated at greater power. The significant correlation with water holding capacity at 10 to 30 cm may be explained by the variability in EM exposure values. The antenna runs thrugh plot one at the ground site, therefore the fields are much higher for this plot than either of the other two (see Appendix A). Water holding capacity at 10 to 30 cm is also highest on this plot (0.38 versus 0.06 or 0.04) creating a significant correlation with the ELF fields without any true cause and effect relationship existing. Because of these trends, both covariates' independence with treatment need to be further examined; the correlations need to be evaluated to determine if there is an actual cause and effect relationship between the covariates and the ELF field. No conclusive evidence indicates that this is true at this time.

These three covariates were able to explain all existing site differences (p=0.05) as well as a site-year interaction (p=0.01). Yearly differences, however, remained significant (p<0.001) (Table 2.13). To account for this time dependent trend, individual seedling height for the respective previous years were predicted from Lundgren and Dolid's monomolecular exponential function (1970). The residuals (observed individual tree height - predicted tree height) were introduced as an additional covariate. Although yearly differences still remained significant (p<0.001) the mean square error for site (error in the system not explained by the model) was reduced substantially. This reduction in mean square error affects the amount of change required in order to detect any possible effects due to the ELF fields. Without this covariate, the detection limit for site differences at the alpha = 0.05 level is 2.59 cm and with the inclusion of the covariate it is 1.53 cm.

The significant time factor is not surprising based on the young age of the seedlings. Considering the typical sigmoid growth curve (Figure 2.4), the seedling heights are most probably still in the exponential portion of the curve. One could not expect to see similar amounts of growth from year to year until later in time when growth is slowing and more linear in shape. Correlations were calculated between EM field strengths for each seedling and the corresponding total seasonal height growth across the three years. Significant correlations (p=0.05) were

found at the antenna site with the transverse fields (V/m) (r=.2626), longitudinal fields (mV/m) (r=.5925), and the magnetic flux (mG) (r=.4720). At the control site there also was a significant correlation (p=0.05) with the east-west running longitudinal fields (mV/m) (r=.5667). These correlations may also be explained by the young age of the seedlings and the fact that the amount of seasonal height growth is still increasing substantially each year. These increases in total seasonal growth are matched with steadily increasing EM field strengths. There are no significant differences in height growth between the study sites (the control site was neither significantly different from the ground or the antenna sites), and although significant correlations with EM fields exist, further monitoring is required before a cause and effect relationship can be determined.

Annual diameter growth

In diameter growth analyses, the current season's site physical, chemical and climatic data explained more site and yearly variation than the information from the previous season. This is consistent with the physiological nature of the seedlings. Thus, in diameter growth analyses, average annual growth from 1985, 1986, 1987, and 1988 were used in the analyses. Initial analysis of variance (without the use of covariates) found strong significant differences among sites and among study years ($p<0.0001$). There also was a significant interaction between study sites and years ($p<0.0001$) indicating that the trends in growth on the sites were not constant from year to year (Table 2.13).

No covariates had been previously identified as successfully explaining either site or year differences. An intensive variable screening as described in Mroz et al. (1988) was conducted and the four variables able to explain the greatest amount of variation were: air temperature degree days through August (on a 4.4° basis), total Kjeldahl nitrogen in July, minimum air temperature in May, and available water at 10cm in the month of August. The selection of climatic variables is consistent with the fact that cambial growth begins a little later than shoot elongation (which begins in mid-April) and is only two-thirds completed when shoot growth ceases (end of July). The need to include variables to account for soil nutrient differences and possible moisture stresses is also consistent with other covariate selections.

As discussed elsewhere, the covariates selected need to be independent of EM fields. At the ground site, available water at 10 cm during August was significantly correlated (p=.05) with the longitudinal fields (mV/m) (r=.4818). At the antenna site air temperature degree days through August (4.4° C basis) and available water at 10 cm in August were significantly correlated (p=0.05) with the transverse fields (V/m) (r=.7685 and r=.8853, respectively), longitudinal fields (mV/m) (r=.7856 and r=.9006,

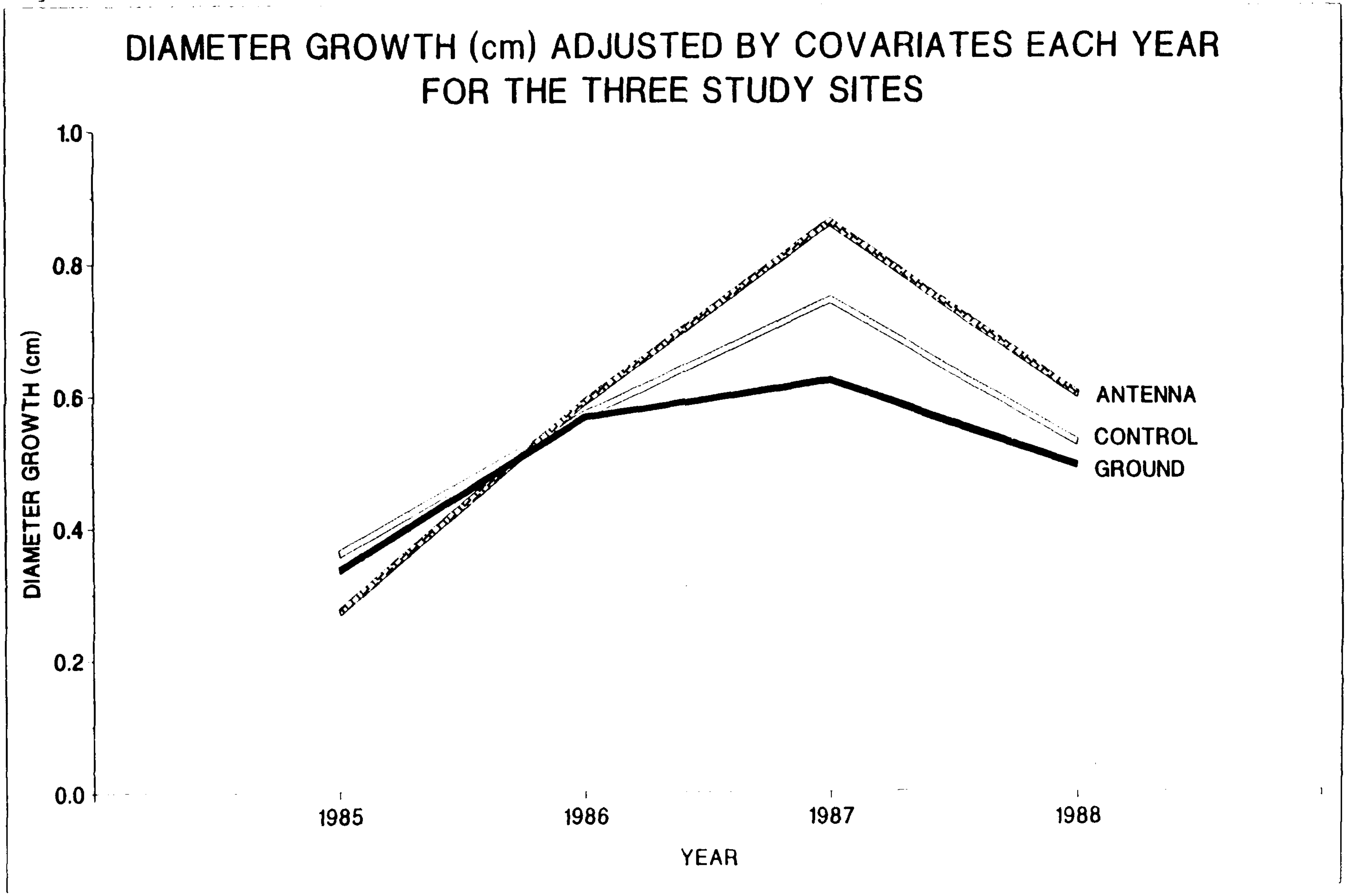
respectively), and the magnetic flux (mG) (r=.8139 and r=.9048). At the control site air temperature degree days through August (4.4^{o} C basis) and available water at 10 cm in August were significantly correlated (p=0.05) with the longitudinal fields (mV/m) (r=.7903 and r=.5387, respectively).

Air temperature degree days through August (4.4^{o} C basis) can probably be attributed to the linear warming trend that exists from 1985 to 1988 as discussed earlier. The accumulated number of degree days has increased each successive year. Available water in August was significantly correlated (p=0.05) with at least one type of ELF field at each site. Although a positive linear trend exist in the data (available water increases from 1985 to 1988) at the antenna site where the correlations are highest, no such trends can be found at the ground site. This variable is a function of soil moisture, bulk density, and precipitation and because of these properties, this variable needs to be further monitored to determine if a true relationship with ELF fields does exist.

With these covariates site and year differences were nonsignificant (p=.05), but a site-year interaction remained significant (p<.001) (Table 2.13). Because of the existence of a significant interaction, multiple range tests were employed to look at diameter growth on each site during each study year. In 1985 there was no significant difference (p=.05) between the ground and control sites. In 1986 there was no significant difference (p=.05) among all three study sites, yet in 1987 all three sites were significantly different from each other (p=.05). In 1988 the ground and control sites were nonsignificant at the alpha=.05 level and at the alpha=.01 level all three sites were not significantly different. The soil, site, and climatological data are not sufficiently explaining existing differences among site and years by themselves. There does appear to be some "noise" in the data; the trends of diameter growth across time on any given site are not consistent nor is the rankings of diameter growth among the three sites in any given year (see Figure 2.3). Diameter growth tends to be affected by competition from other seedlings for resources and a measure of this competition seems to be the next logical step in attempting to explain these differences.

At this point, diameter growth differences do exist and some of the covariates explaining a portion of these differences can not be assumed to be independent of the ELF fields. Correlations were calculated between EM field strengths for each seedling and the total seasonal diameter growth for each seedling. Significant correlations (p=0.05) were found with the longitudinal fields (mV/m) (r=.2446) and the magnetic flux (mG0 (r=.1477). These correlations, although small, suggest that some relationship between the ELF fields and seasonal diameter growth exists, but until the variation in the system can be further examined, differences in seasonal diameter growth can not be attributed solely to the ELF field exposures.

Figure 2.3


DIAMETER GROWTH (cm) ADJUSTED BY COVARIATES EACH YEAR
FOR THE THREE STUDY SITES
DIAMETER GROWTH (cm)
1.0
0.8
0.6
0.4
0.2
0.0
1985
1986
1987
1988
YEAR
ANTENNA
CONTROL
GROUND

Seasonal Pattern of Height Growth

Height growth models based on incremental seasonal growth of the leading shoot were developed to evaluate changes that might occur in the pattern or timing of seedling height growth among the three study sites or from year to year (Mroz et al 1988). The model is comprised of two components. Previous work done in this field by Perala (1985) found that climatic conditions were more useful predictors and could explain much of the variation in the timing and the amount of shoot elongation among sites. In this study air temperature degree days (on a 4.4° C basis) is the first component. To further explain the variation in the system a second component was added to the model. A negative exponential component modifies the expected growth based on soil water tension (Zahner 1963). The model form is as follows:

$$g_t = \left[\left(1 - e^{-b_1 * ATDD_2^{\;b_2 * (TGRO^{b_3})}}\right) - \left(1 - e^{-b_1 * ATDD_1^{\;b_2 * (TGRO^{b_3})}}\right) \right] * (TGRO) * \left(e^{b_4 * (MT - .101)}\right)$$

where

g_t	= amount of shoot growth (0.1 cm) occurring in week t
TGRO	= expected total shoot growth (0.1 cm) in the growing season
$ATDD_1$	= air temperature degree days (4.4° C) to the beginning of week t
$ATDD_2$	= air temperature degree days (4.4° C) to the end of week t
MT	= average soil water tension for week t (if actual soil water tension is less that .101 -MPa, mt was set to .101 -MPa for model development)
b_1, b_2, b_3	= estimated coefficients for air temperature degree days component
b_4	= estimated coefficient for moisture stress component

Table 2.14 contains the values for the estimated coefficients.

Table 2.14. Coefficient estimates for the red pine height growth model.

	Coefficient Estimate	Asymptotic 95% Confidence Interval
b_1	0.0069	(0.0068, 0.0070)
b_2	1.7601	(-2.1119, -1.4083)
b_3	0.4024	(0.3633, 0.4413)
b_4	-1.7601	(-2.1119, -1.4083)

The component

$$b_2 * TGRO^{b_3}$$

is based on the concept that the duration of shoot growth varies with the amount of total seasonal growth (Perala 1985); as total shoot growth increases, the duration of growth increases as well. Tests show this to be highly significant.

As discussed in the hardwoods section, the height growth model provides an weekly residual for each seedling at each site each year. This residual is calculated in the same manner as described in the seedling height growth section of the covariate analyses. If there is any change attributable to ELF in the height growth pattern which was established from previous years, the residual will either increase or decrease. Figures 2.4 to 2.6 illustrate the observed and predicted cumulative growths for 1988 on the three study sites. Although the cumulative curves may mask any possible absolute differences, the advantage in standardizing is that established patterns in growth may be examined. Examination of the residuals from 1986 through 1988 at each study site found no significant differences (p=0.05) between the observed and predicted seasonal height growth patterns (Table 2.15).

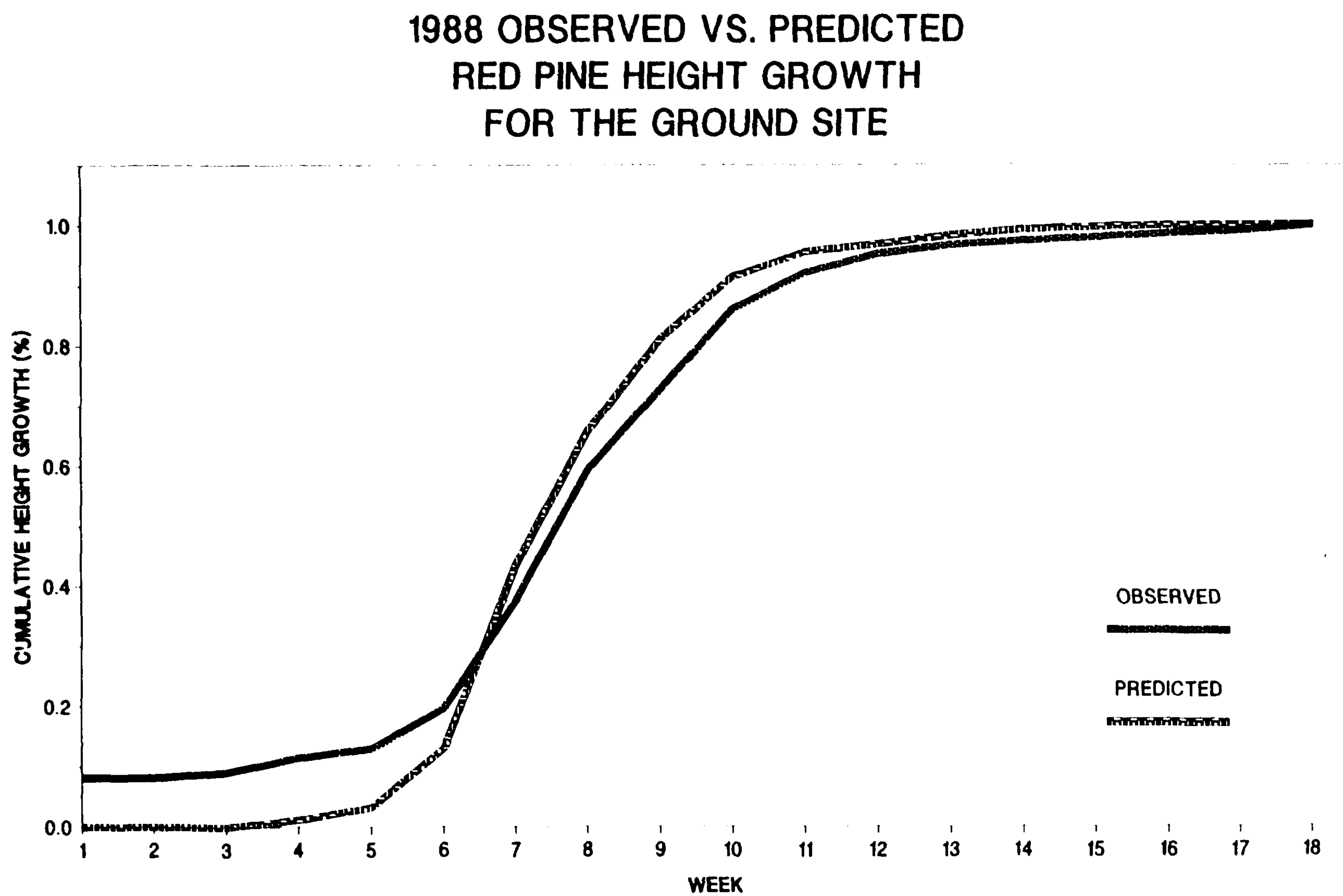
Possible changes in height growth patterns may also be evaluated through correlation analysis with ELF field exposure variables. Each seedling's position was mapped and EM field strengths were calculated for individual seedlings. Correlations were calculated between the residuals from the height growth model and the strengths of EM exposuress to each seedling across the three years of study. No significant correlations between the residual and the ELF fields (p=0.05) were found at the ground site, but significant correlations (p=0.05) were found at the antenna and control sites. To determine if these significant correlations were distance related correlations were run on 1988 data only and the significant correlations (p=0.05) disappeared. Based on both of these analyses, there appears to be no ELF field effects on seasonal height growth patterns of red pine seedlings at this time.

Red Pine Foliage

The objective of this work is to determine 1) whether ELF fields have any effect on the nutrition of red pine seedlings and 2) whether red pine foliar nutrient concentrations can be useful in explaining site differences in red pine growth rates.

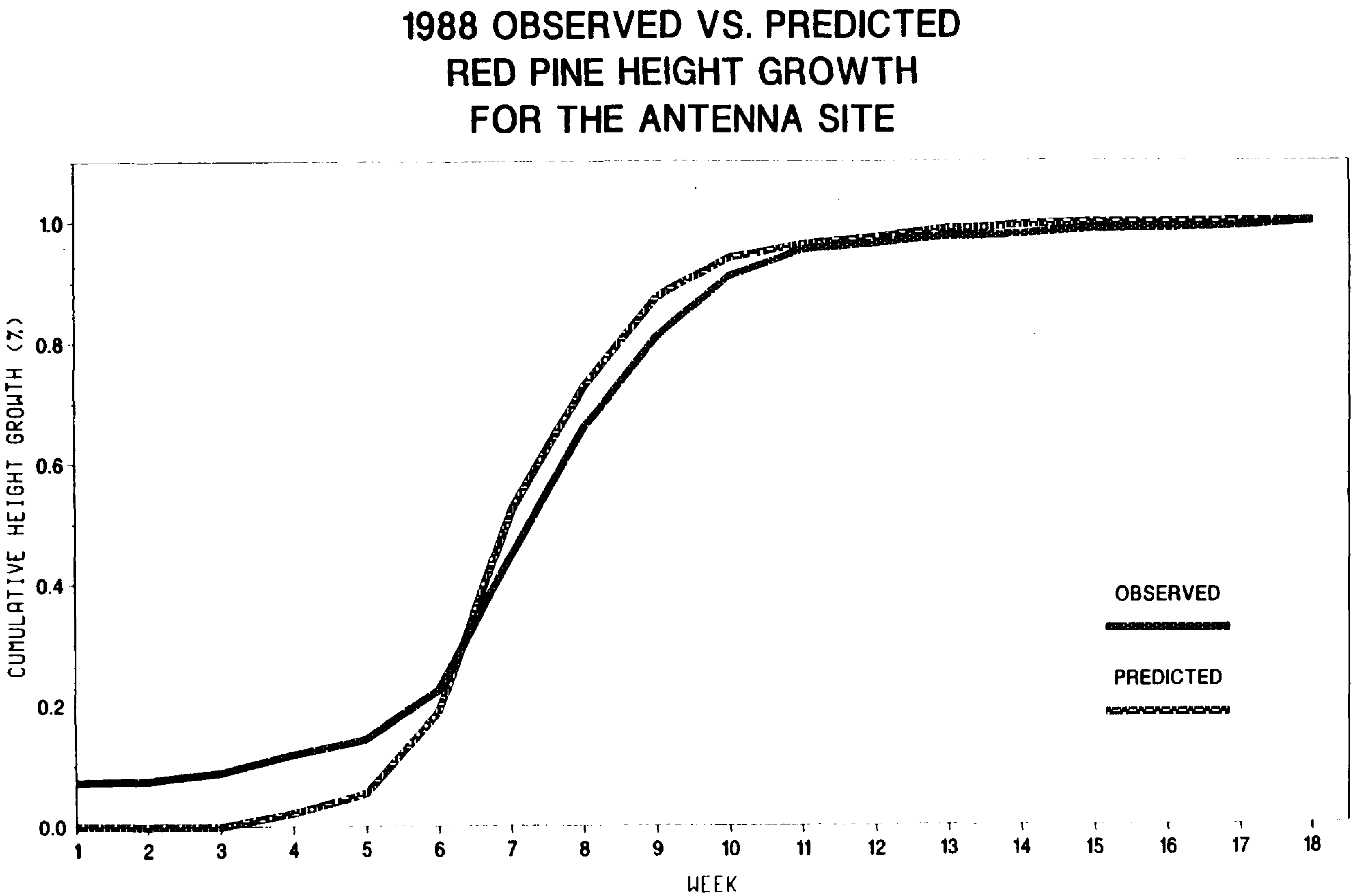
Red pine foliage was collected from 50 seedlings per site at the time of planting, from 45 seedlings per site in October of 1984 and from 15 seedlings per site in October of the 1985 through 1988 field seasons. These sample sizes correspond to the number of seedlings used in leaf water potential studies and mycorrhizae studies with multiple measurements made on each seedling. At each collection period, one year old needles were taken from seedlings, dried at 60^{0} C and analyzed for concentrations of N, P, K, Ca and Mg.

Figure 2.4



1988 OBSERVED VS. PREDICTED
RED PINE HEIGHT GROWTH
FOR THE GROUND SITE
CUMULATIVE HEIGHT GROWTH (%)
1.0
0.8
0.6
0.4
0.2
0.0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
WEEK
OBSERVED
PREDICTED

Figure 2.5



1988 OBSERVED VS. PREDICTED
RED PINE HEIGHT GROWTH
FOR THE ANTENNA SITE
CUMULATIVE HEIGHT GROWTH (%)
1.0
0.8
0.6
0.4
0.2
0.0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
WEEK
OBSERVED
PREDICTED

Figure 2.6

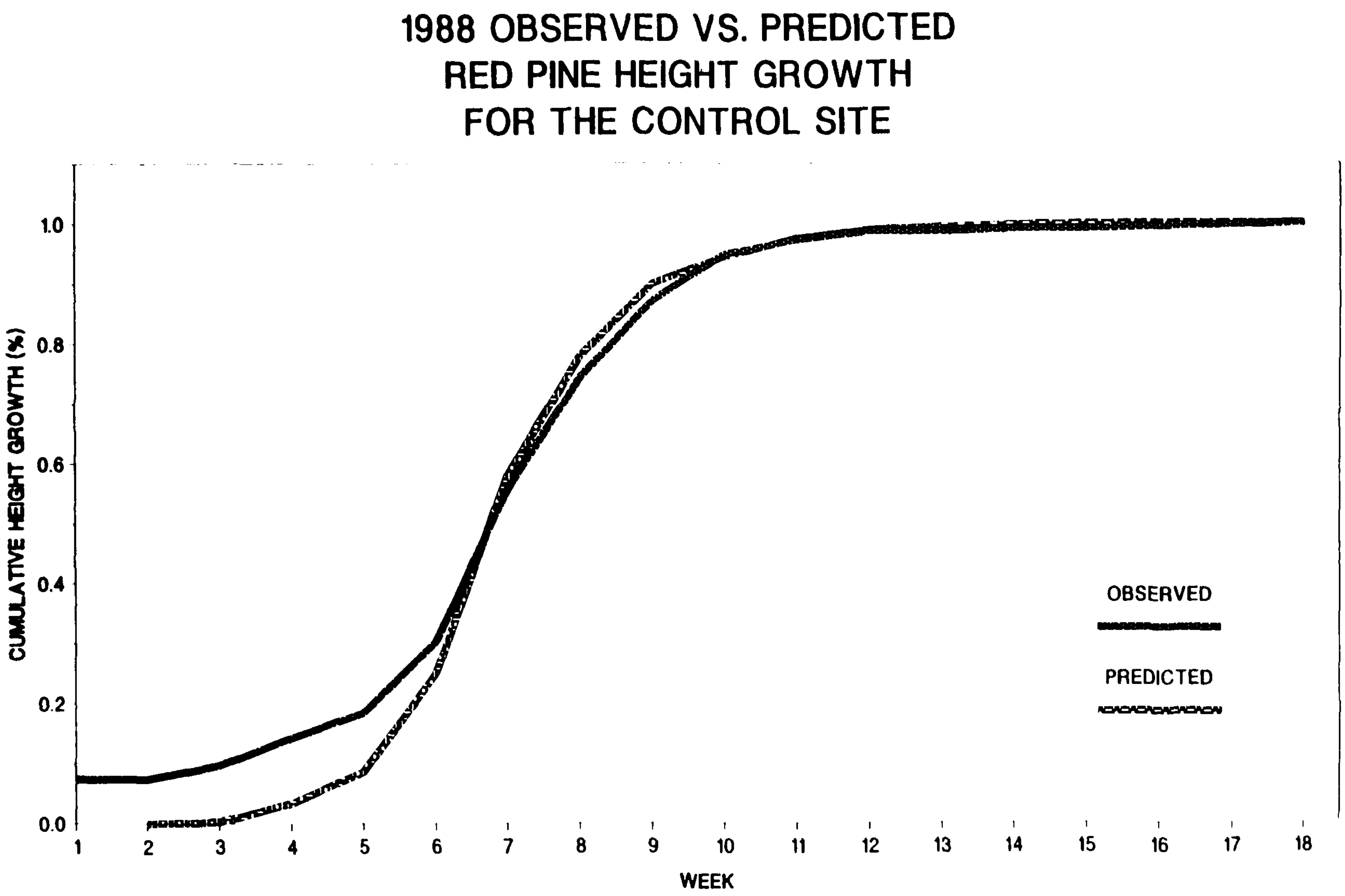

1988 OBSERVED VS. PREDICTED
RED PINE HEIGHT GROWTH
FOR THE CONTROL SITE
CUMULATIVE HEIGHT GROWTH (%)
0.0
0.2
0.4
0.6
0.8
1.0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18
WEEK
OBSERVED
PREDICTED

Table 2.15. Residual analysis from the height growth model for the ground, antenna, and control sites in 1986, 1987, and 1988.

	Average Residual (cm)	Studentized 95% Confidence Interval
Ground		
1986	-0.0568	(-0.1219, 0.0083)
1987	-0.0762	(-0.2314, 0.0790)
1988	-0.0400	(-0.2791, 0.1994)
Antenna		
1986	-0.1093	(-0.1572, -0.0610)
1987	-0.0708	(-0.0708, 0.0518)
1988	0.0427	(-0.2264, 0.3118)
Control		
1986	-0.0687	(-0.1826, 0.0452)
1987	-0.0562	(-0.2021, 0.0897)
1988	-0.0600	(-0.0600, 0.1384)

Progress

At this time, foliage nutrient analysis has been completed for samples taken at planting through 1988 (Table 2.16). In general, most nutrient concentrations are above or near levels reported for adequate growth of red pine. Critical foliar concentration levels have been reported for Mg (0.05%), and Ca (0.12%), while concentrations of N above 1.0% and P above 0.16% have been found to be adequate for growth in plantations (Stone and Leaf, 1967; Hoyle and Mader, 1964; Alban, 1974). Only K concentrations are low, being in the range that has been reported for low to deficient levels for red pine in plantations (0.30-0.51%) (Hieberg and Leaf,1961; Madgwick, 1964). Nutrients are ranked in the order: N > K > Ca > P > Mg for all years sampled.

No attempts have been made to include foliage nutrient concentrations in red pine growth analyses at this time. Analyses to examine site and year differences with and without covariates show year differences for all nutrients and site differences in foliar N and P that could not be explained using covariate analyses (Table 2.17). In past years the use of various covariates, notably mycorrhizae per gram of root weight and various soil nutrients, helped to explain most of the year and year by site interactions. However, these were less effective in explaining differences with the 1988 data added to the analyses. In evaluating covariates for independence from treatment effect, we found many soil nutrients to be weakly but significantly related to EM fields on the sites (Table 2.18). This is probably a coincidental trend due to the limited number of years (1986-1988) for which EM field data are available and the gradually increasing treatment level during the antenna test period. When the EM treatment is more constant (in 1989 and 1990), and additional years of data are available, we will be better able to evaluate these relationships.

The effective performance of soil nutrients in past years in explaining differences in foliar nutrients indicated an opportunity to examine other site ambient factors and their relation to foliar concentration. The approach that has been successfully used by Bicklehaupt et al. (1979) was adopted to try to explain foliar nutrient differences among sites and years. They found that cumulative degree days and precipitation in the current year and in the period after cessation of height growth in the previous year (due to determinant growth of red pine) was useful in explaining yearly fluctuations in foliar nutrient levels. Using this approach, summations of air temperature degree days and precipitation for the period April 15 through August 31 of the current year plus July 15 through September 30 of the previous year were calculated and correlations calculated with foliar nutrients, soil nutrients and EM fields. Degree day and precipitation summations for the periods defined above were then used to predict annual foliar nutrient deviation from the

Table 2.16. Foliage nutrient content for red pine seedlings at ELF study sites at the time of planting and four years afterwards.

Site	N	P	K	Ca	Mg
AT PLANTING					
Ground	1.12	0.14	0.40	0.22	0.12
Antenna	1.16	0.14	0.39	0.20	0.12
Control	1.15	0.14	0.39	0.22	0.12
1984					
Ground	1.42	0.15	0.49	0.30	0.13
Antenna	1.50	0.16	0.50	0.31	0.14
Control	1.33	0.15	0.46	0.30	0.13
1985					
Ground	1.43	0.16	0.51	0.20	0.09
Antenna	1.09	0.13	0.55	0.18	0.08
Control	1.61	0.18	0.55	0.23	0.10
1986					
Ground	1.42	0.13	0.47	0.19	0.08
Antenna	1.59	0.14	0.51	0.18	0.08
Control	1.34	0.13	0.49	0.23	0.09
1987					
Ground	1.06	0.11	0.34	0.21	0.09
Antenna	1.10	0.12	0.33	0.24	0.09
Control	1.04	0.12	0.36	0.23	0.09
1988					
Ground	1.16	0.14	0.58	0.25	0.11
Antenna	1.27	0.15	0.56	0.22	0.10
Control	1.17	0.13	0.48	0.25	0.09

Table 2.17. Results of red pine foliage nutrient covariate analyses.

	P Value				
	CA	MG	K	N	P
Without Covariates					
Site	.193	.110	.199	.019	.009
Year	.015	.000	.000	.000	.001
Year x Site	.261	.002	.001	.160	.716
With Mycorrhizal Per Gram of Root Weight					
Site			.248	.006	.032
Year			.000	.000	.004
Year x Site			.001	.232	.692
With Soil Phosphorous ($Kg \cdot ha^{-1}$)					
Site	.681	.046			
Year	.067	.000			
Year x Site	.421	.002			
With Soil Nitrogen and Phosphorous ($Kg \cdot ha^{-1}$					
Site			.078		
Year			.005		
Year x Site			.008		
With Soil Magnesium and Phosphorous					
Site				.005	
Year				.000	
Year x Site				.451	
With Soil Calcium and Nitrogen					
Site					.012
Year					.001
Year x Site					.730

Table 2.18. Correlations between red pine foliar nutrients and soil nutrients, ambient variables and EM fields.

	TRANS[a]	LONG[b]	MAGFLX[c]	PRECSUM[d]	ATSUM[e]
Foliar N[f]	-.12	-.13	-.14	-.06	-.41*
Foliar P	.01	.06	.04	-.29*	.08
Foliar K	.29*	.19*	.31*	-.61*	.02
Foliar Ca	.10	.05	.10	-.16	.28*
Foliar Mg	.23*	.17	.26*	-.38*	.26*
Soil N[g]	.24*	.10	.28*		
Soil P	-.13	-.19*	-.08		
Soil K	.41*	.27*	.45*		
Soil Ca	.42*	.29*	.43*		
Soil Mg	.36*	.23*	.37*		
PRECSUM	-.30*	-.23*	-.30*		
ATSUM	-.07	-.18*	-.04		

* Significant correlation ($p < 0.05$)
[a] Transverse EM field, east-west antenna leg operation.
[b] Longitudinal EM field, east-west antenna leg operation.
[c] Magnetic flux, east-west antenna leg operation.
[d] Cumulative precipitation, 7/15 - 9/30 previous year plus 4/15-8/31 current year.
[e] Cumulative total of air temperature degree days, 7/15 - 9/30 previous year plus 4/15 - 8/31 current year.
[f] Parts per million
[g] kilograms per hectare

where

y = the deviation of the foliar nutrient value of 45 trees for each year from the 3 year foliar nutrient average

x_1 = deviation of annual precipitation summation from the 3 year average precipitation summation for the period describe above and

x_2 = deviation of annual degree day summation from the 3 year average degree day summation for the period describe above

The predicted deviation from the equation was then added to each foliar nutrient value to arrive at a adjusted nutrient value. However, the appropriateness of using this approach is unclear

because the independant variables were found to be weakly but significantly correlated to EM field strength (Table 1.18). Once again this is probably due to the limited number of years for which EM data are available and coincidental trends in antenna testing and climate. For example, the test period during which the antenna has slowly been brought to full power has also been a period subjected to a gradual warming trend causing this correlation. We expect this particular relationship to cease in 1989 as the antenna became operational while temperature decreased compared to previous years (Table 1.3). Thus, we felt it necessary to continue with the analysis for red pine foliar nutrients. To do this, the adjusted foliar nutrient values were then examined with analysis of variance. For all nutrients, all year and year by site differences were explained to non significant levels ($p > 0.05$) by the adjusted values (Table 2.19).

Table 2.19. Significance levels from analysis of variance for adjusted red pine foliar nutrient concentrations.

	P Value				
	CA	MG	N	P	K
Site	.193	.110	.199	.019	.009
Year	.143	.375	.803	.996	.809
Year x Site	.277	.671	.924	.999	.981

However, site differences still remain for N and P. Since this approach is better suited to account for yearly variation in the foliar analysis rather than among sites, soil N and soil P (Kg/Ha) were used as covariates in an attempt to explain the foliar N and P site differnces. These variables did not, however, explain the differences to non significant levels ($p > 0.05$).

At this point, additional work needs to be done to find covariates that would explain site differences in foliar N an P. Ratios of certain soil nutrients and other site factors such as seedling microsite will be considered. However, the correlations between soil nutrients and the climatic variables and the EM fields needs to be monitored closely to determine whether these potential covariates are truely independent of EM effects. Additional years of data collection and constant antenna operation in future years will allow us to better evaluate these relationships. Until that time, we cannot ascertain whether red pine foliar nutrients are independent of EM fields.

Leaf Water Potential*

Leaf water potential (LWP) is a measure of the internal moisture status of plants and can be a useful measure of overall physiological condition. The overall objective of the red pine LWP study is to quantify the LWP/growth relationship prior to and after activation of the ELF antenna and evaluate the usefulness of LWP as a covariate in the growth analysis of red pine.

Optimum tree growth is dependant on many factors such as healthy root systems which allow adequate uptake of water and nutrients. Similarly, the aboveground biomass must function properly to translocate water and nutrients from the roots to provide photosynthate for growth. A physiological change that would affect the function of the root system and aboveground biomass may also affect the growth of the plant. Such changes may affect the internal moisture status. Thus, changes in LWP may indicate changes in physiological processes that affect plant growth.

Leaf water potential can also be used to help explain growth differences between sites. Site characteristics such as soil physical and chemical properties, microsite, water holding capacity, and climate have an effect on the growth of red pine. Because red pine exhibits relatively little genetic diversity, seedling growth expresses the potential of a site to provide optimal conditions for growth. The quality of the site is thus reflected in the growth of the seedling. If site quality is not optimum, physiological growth is also not at an optimum level and this may be reflected by LWP.

Finally, LWP values can be used to indicate moisture stress during periods of drought. Extended drought can reduce water uptake and reduce growth and survival of red pine seedlings. The LWP values may help explain differences in year to year growth that are due to drought conditions.

Therefore, LWP reflects the integrated effects of physiological processes and environmental conditions on seedling growth and will be evaluated as a potential covariate in the red pine growth studies.

Sampling and Data Collection

LWP sampling was conducted in years 1984 - 1989. The red pine seedlings were planted in June 1984 and became established during that growing season. LWP values (MPa) were more negative in 1984 than for 1985 - 1988 due to planting shock and do not accurately reflect LWP of established seedlings. Furthermore, ambient monitoring data are not available for 1984 for use in covariate analysis. Therefore, 1984 LWP data are not included in this analysis.

* This section has been renamed from 'Plant Moisture Stress' to 'Leaf Water Potential' to more accurately describe the internal moisture process and be consistent with current literature terminology as suggested by reviewers.

Sampling in 1989 was conducted biweekly beginning on May 26 and continuing until August 28 at the ground, antenna, and control sites. Sampling was not conducted after this time due to cold temperatures at the scheduled time of sampling and subsequent frozen xylem water; this results in low LWP values that are not an accurate reflection of seedling moisture status. On each sampling date, fifteen actively growing red pines were randomly selected from each site. A one year old needle was cut from each red pine in the pre-dawn hours and immediately placed in a pressure chamber to determine LWP (Richie and Hinckley, 1975). During the daylight hours prior to LWP determination, basal diameter, shoot elongation, total height, and current year needle elongation were measured. The aboveground portion of each sample tree and a portion of the root system were removed from the site the afternoon following LWP determination to obtain aboveground biomass and mycorrhizae counts.

Topographic maps of each plot were developed in 1989 to further describe microsite variation. Computer interpolation of the elevation data then provided a method to assign an elevation to each sample tree provided its location on the plot was known. Because tree location for the sample trees is not available prior to 1988, elevation data are available only for years 1988 and 1989. In addition, soil temperature at 10 cm and air temperature at 1 meter were also recorded at each sample tree location at the time of LWP measurement in 1989 and together with elevation were considered for inclusion in the covariate analysis.

Progress

Leaf water potential values varied between -.16 and -.97 MPa in 1989 (Table 2.20 and Figure 2.7).Becker et al. (1987) reported that LWP values ranging from -.80 to -1.1 MPa did not produce measurable reductions in red pine seedling growth. LWP means for each measurement date are well within or below this range as were the 1985 - 1988 values (Appendix C).

The pattern of LWP within 1989 was similar at the ground and antenna sites while a somewhat different pattern was observed at the control site (Fig. 2.7). The relatively low LWP experienced on June 5 for all sites is probably due to low air temperature at the time of sampling. Cool temperatures effect the viscosity of water which in turn increases the tension with which the water is held. The greatest resistance to internal water flow occurs when temperatures fall below 7 ^{o}C (Grossnickle, 1988). This condition existed during the June 5 sampling (Table 2.21). Similarly, relatively low air temperature (9.6 ^{o}C) resulting in low LWP also occurred at the antenna and ground sites during the August 28 sampling. The most negative LWP (greatest stress) at the antenna and ground sites occurred on July 31 following a period of low soil moisture and precipitation (Table 2.21). However, the sites received considerable rainfall during the week prior to the July 31 sampling, yet LWP values decreased (Fig 2.7, Table 2.21). This may suggest that a recharge period is required before the

precipitation reaches the rooting zone in the soil and water uptake can increase and thus increase LWP.

The highest LWP (least stress) at the antenna and ground sites occurred on August 14 (Fig. 2.7) following abundant rainfall and during a time of high relative humidity (Table 2.21). Although relationships between LWP and climate variables can be observed on some dates for the antenna and ground sites, they are not so obvious at the control. The LWP values at the control on May 25, June 19, and August 28, do not appear to be related to the climatic variables in the same manner as for the antenna and ground sites. In some situations, climatic variables may operate in combination to initiate a response in LWP. Additional work in defining these relationships and a modeling approach may be helpful to further explain variation between LWP and sampling dates.

Table 2.20. Average leaf water potential, 1989 (-MPa) N=15.

Date	Ground		Antenna		Control		Overall
	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std Dev.	
	-MPa						
5/25	.27	.18	.20	.20	.66	.32	.38[a]
6/5	.75	.20	.68	.25	.67	.33	.69[bc]
6/19	.39	.13	.44	.11	.97	.36	.60[b]
7/6	.46	.28	.38	.18	.35	.28	.39[a]
7/17	.42	.32	.26	.15	.52	.38	.40[a]
7/31	.79	.29	.82	.22	.62	.26	.74[c]
8/14	.19	.08	.16	.07	.45	.22	.26[c]
8/28	.75	.30	.69	.27	.30	.20	.52[b]
Overall	.44[x]		.38[x]		.47[x]		

Values followed by the same letter are not significantly different (p=0.05).

Analysis of variance was conducted in order to test differences between LWP and measurement dates and sites in 1989. Significant differences (p=0.05) were found in 1989 between measurement dates and in the date by site interaction, but differences between sites were not significant (Table 2.20). This same result was also reported for the 1988 LWP data (Mroz, et. al., 1989).

The combined data for years 1985-1989 were then examined through analysis of variance to evaluate LWP differences between sites and years. The design and ANOVA table for this analysis are presented in Table 2.22).

Figure 2.7

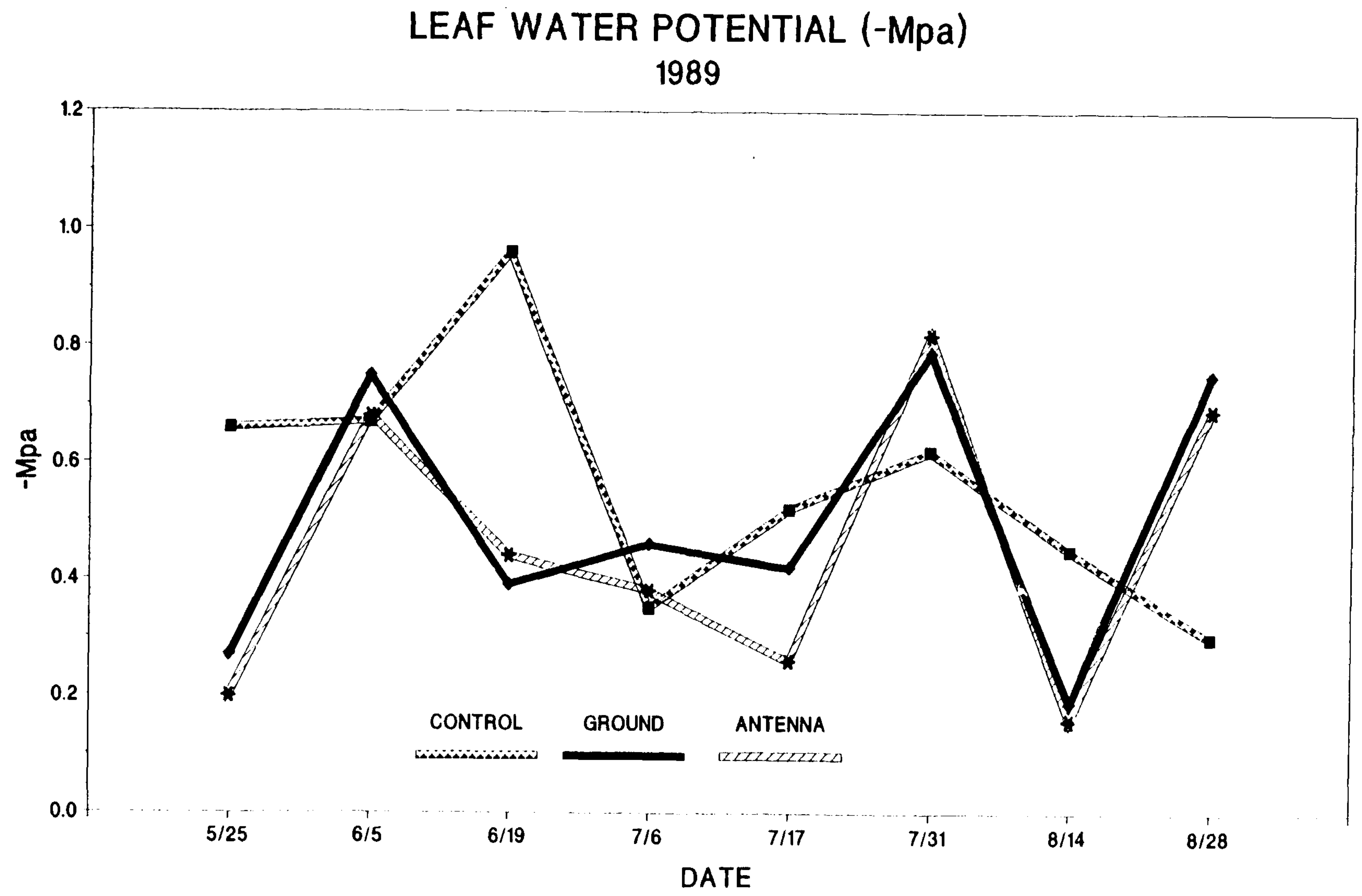

LEAF WATER POTENTIAL (-Mpa)
1989
-Mpa
1.2
1.0
0.8
0.6
0.4
0.2
0.0
CONTROL
GROUND
ANTENNA
5/25
6/5
6/19
7/6
7/17
7/31
8/14
8/28
DATE

Table 2.21. Ambient Conditions for 1989 LWP measurements dates. (All sites combined)

Date	Air*[a] Temp.	Air Temp. Minimum	Air Temp. Maximum	Relative* Humidity %	Relative Humidity % Minimum	Soil* Temp. 10 cm	Soil* Moisture 10 cm	Rainfall[b] (in.)
5/25	17.0	13.6	23.2	41.0	18.0	----	14.4	.46
6/5	8.9	0.3	19.7	62.2	24.6	13.2	16.3	1.69
6/19	19.8	11.7	29.9	65.6	29.5	16.1	16.8	2.86
7/6	22.2	11.1	33.1	63.7	38.0	19.6	11.8	.35
7/17	19.3	11.9	28.8	57.0	38.0	18.3	6.4	.17
7/31	18.9	14.7	25.5	69.9	30.5	17.5	9.5	.97
8/14	16.5	15.0	18.3	82.7	57.5	17.4	15.0	1.98
8/28	15.3	9.6	21.8	67.9	41.7	17.2	11.6	.31

* Daily Average
a Temperature °C
b Total precipitation between sampling dates or prior 14 day period.

Table 2.22 Anova table for the analysis of 1985 - 1989 leaf water potential data.

Source of Variation	df	SS	MS	F-Ratio
Year	3	SS(Y)	MS(Y)	MS(Y)/MS(E1)
Date w Year (E1)	32	SS(E1)	MS(E1)	MS(E1)/MS(WR)
Site	2	SS(S)	MS(S)	MS(S)/MS(E2)
Site by Year	8	SS(SY)	MS(SY)	MS(SY)/MS(E2)
Date w Year by Site (E2)	64	SS(E2)	MS(E2)	MS(E2)/MS(WR)
Within + Residual (WR)	1550	SS(WR)	MS(WR)	

w = within

Significant differences (p=0.05) were found between years and the date interactions with year and site, however, differences between sites and the year by site interaction were not significant. Because LWP is being considered as a possible covariate in the red pine growth analysis we must determine whether LWP is independent of ELF fields. This can be accomplished by analysis of covariance. If covariates can explain these differences then we can conclude that LWP is independent of ELF fields.

The significant differences found in this year's analysis were the same as those reported for years 1985-1988 (Mroz et. al., 1989). In that analysis, average daily air temperature and tree age were used as covariates which explained differences among years. However, they did not explain the differences in the date interactions with site and year. The same covariates were used this year in the analysis of 1985-1989 data with the same result (Table 2.23).

Table 2.23. Significance levels from analysis of covariance for LWP with average daily temperature and tree age as covariates.

Factor	P-value
Year	.130
Date within Year	.000
Site	.164
Site by Year	.690
Date within Year by Site	.000

Additional covariates, tree elevation, and air and soil temperature at each sample tree, were then considered for

inclusion in the analysis. Correlations between LWP and each potential covariate were calculated (Table 2.24).

Table 2.24. Correlations between LWP and selected variables considered for inclusion in the analysis of covariance.

Variable	Correlation
Average daily air temperature (°C)	.48*
Tree age	.34*
Tree elevation (M), 1988 and 1989 only	.13*
Air temperature at sample tree (°C), 1989 only	.03
Soil temperature (10 cm) at sample tree (°C)	.08

* Significant at p=0.05

Variables with significant (p=0.05) correlations were selected for inclusion in the analysis. However, these additional covariates did not explain the date interactions with year and site. If site and climatic variables cannot explain these differences, it is then appropriate to consider the EM fields in the analysis. Correlations were then calculated between LWP and the various EM fields but the correlations were non significant (p=0.05) in all cases. EM field intensities (V/m, mV/m, or mG/m) interpolated from the EM measurement points to the sample tree locations were used in the correlations. Hours of antenna operation between sampling dates combined with the intensity data should provide a better estimate of sample tree exposure to the EM fields. At this time, these calculations are not complete and this work will continue in the coming year. In addition, the fact that climatic and other site variables have thus far not been able to account for the differences in the date interactions with site and years warrants further efforts to find relationships and interactions between these factors and LWP. Additional work with the elevation data and climatic data will also continue in the coming year.

Summary

LWP values in 1989 were within published limits that do not produce measurable reductions in red pine growth. Through the use of covariate analysis, no significant differences remain among sites, years, or in the year by site interaction indicating that the EM fields had no detectable effect on LWP for these factors. However, significant differences do remain for the date within year and the date within year by site interactions. Additional work with climatic data, site data, and the EM fields

will be necessary to determine whether the ELF system is effecting LWP between sampling dates within years.

Red Pine Seedling Mortality - Armillaria Root Disease

Armillaria root disease mortality among the planted red pine seedlings was first noted in 1986, the third year following stand conversion. In 1989, Armillaria root disease was still the only fatal infectious disease documented in the plantations. We are evaluating epidemiological factors controlling the rate of seedling mortality caused by this disease, for several reasons. First, certain Armillaria spp. are well known for their ability to kill host plants subjected to various forms of stress. Wherever clones of pathogenic Armillaria spp. are active, root disease will be a sensitive biological indicator of the extent to which red pine seedlings are stressed by any agent, including ELF electromagnetic fields. Second, there is excellent reason to expect that additional mortality due to this disease will occur with increasing plantation age. Adequate woody foodbases (stumps and their root systems) occur on the sites, and clones of the highly pathogenic Armillaria ostoyae (NABS I, North American Biological Species I) have been identified. Finally, the rate of mortality has increased markedly since 1987 on a number of the plot replicates (especially at the Antenna and Ground sites).

The causal agent of this disease is at least one member of the Armillaria species complex (Wargo and Shaw III 1985). These fungi cause a white rot type of decay in woody debris, stumps and moribund root systems which are colonized by means of airborne spores and/or cord-like rhizomorphs. Rhizomorphs grow through the soil, utilizing energy from the decay of one foodbase to colonize the next. Conifer seedlings may be colonized and killed by Armillaria spp., either through infection by rhizomorphs or by seedling root growth into contact with decaying foodbases.

Seedling vulnerability depends upon several site and biological factors. First, distribution of mortality has been related to the spacing and size of hardwood stump foodbases (Pronos and Patton 1977). Seedling vulnerability increases with proximity to infested foodbases. Second, rhizomorph growth is most efficient in well-aerated light-textured soils with low rock content (Rishbeth 1978, Singh 1981). Third, seedling vulnerability is increased by the addition of any physiological stress, such as severe drought or competition. Because ELF fields represent a possible additional source of stress, the underlying factors governing Armillaria root disease development on the three plantation plots will be evaluated, and the rate of spread of Armillaria clones in the study plantations will be estimated. In this way, the role played by ELF fields in determining rates of root disease mortality can be determined.

The evaluation of Armillaria root disease development in the plantation plots is divided into three areas: 1) identification of the responsible pathogenic Armillaria species (as well as any non-pathogenic species) occurring in each plantation plot quarter-replicate, 2) estimation of Armillaria clone extension in

each quarter-replicate, based on mapped distribution of cultures obtained from mortality and basidiome (mushroom) collections, and 3) evaluation of site factors and ambient conditions contributing to annual levels of disease. The overall null hypothesis tested in this phase of the study is:

> H_O: There is no difference in the rate of development of Armillaria root disease on red pine seedlings before and after the ELF antenna becomes operational which can not be explained by factors other than ELF field levels.

Sampling and Data Collection

Armillaria root disease mortality has been monitored closely since it first began to develop during the 1986 field season. The position of each seedling killed by Armillaria root disease has been marked in the field and mapped for permanent reference. As soon as seedlings develop the gray-green foliage color symptomatic of fatal decline, they are checked for the presence of characteristic mycelial fans under the bark at the root collar. Infected seedlings are then returned to the laboratory for cultural isolation of the pathogen onto potato dextrose agar in Petri dishes. Armillaria isolates are maintained indefinitely for reference.

Because of the primary importance of stumps and their associated root systems as foodbases for Armillaria, it was necessary to quantify the stump populations on the ELF plantations in order to explain the distribution of root disease on red pine seedlings. Each plantation plot was therefore represented as 12 quarter-replicates for purposes of mapping and analysis. In 1987, the location of each stump or dead seedling was mapped on a Cartesian coordinate system, using right angle prisms.

The genetic unit of study in populations of Armillaria spp. is the clone (the vegetative individual) which grows and extends itself from one foodbase to the next in the form of rhizomorphs. Clones can be distinguished in the laboratory through cultural confrontations on three percent malt extract agar between isolates derived from dead seedlings, decaying stumps, or Armillaria basidiomes. Isolates from the same clone grow together and intermingle freely, whereas isolates representing different clones form lines of demarcation where they grow into contact with one another (Kile 1986, Korhonen 1978, Mallett and Hiratsuka 1986, Siepmann 1985). Armillaria clones may be identified to genetically intersterile species in the laboratory by cultural confrontations on malt extract agar between (diploid) representatives of each clone and single-basidiospore isolates (haploid tester strains) representing known Armillaria spp. (Siepmann 1987). The normally fluffy white tester strains become dark and crusty when confronted with compatible diploid isolates of the same species. More reliably, reference tester strains should be confronted in culture with haploid tester strains representing clones from the field. The latter can be derived

either as single spore isolates from basidiomes collected in the field or from basidiomes obtained by fruiting diploid isolates in the laboratory on autoclaved orange sections. Basidiospore collections can be frozen in water for single-sporing at a later date.

Sorting the Armillaria isolates obtained from 1) dying seedlings and 2) associated decaying foodbases into clones (and these clones into species) is an important step toward explaining the distribution of mortality on the plots, and will also help to confirm or reject hardwood species foodbase preferences suggested by regression analysis. Identification of clones to species is imperative in light of differences in rate of root disease development among the 12 quarter-replicates comprising each plantation plot. Armillaria spp. differ in pathogenicity to conifers and hardwoods (Korhonen 1978, Rishbeth 1985) to such an extent that differences in root disease observed among the plantation plots might be explained if the quarter-replicates are dominated by different Armillaria spp. For example, Rishbeth (1985) found that the host ranges of A. mellea isolates were more likely to encompass hardwoods as well as conifers than were the host ranges of A. ostoyae isolates. Though both species are considered to be highly pathogenic toward pines, Rishbeth found that his isolates of A. mellea were slightly more virulent toward Scots pine than were his isolates of A. ostoyae.

Multiple regression analysis is being used to identify factors which help to explain differences in Armillaria root disease mortality across space and time. Regression models are being derived which relate characteristics of host and site as well as ambient conditions (including estimates of ELF field strength), as independent variables, to the dependent variable, seedling mortality percent on the quarter-replicates. The overall significance of each tested model is evaluated using the F test for the associated analysis of variance, and the contributions of individual independent variables in each model are evaluated using the corresponding t statistic. The predictive capability of each model is indicated by its associated r^2 value. Differences among years will be evaluated by incorporating a set of classification (dummy) variables (Searle, 1971) into the regression model. This produces a model identical in structure to the analysis of covariance model. The interpretation can be quite different because we are concerned with both the classification and continuous (analogous to covariates) variables, while the classical analysis of covariance model uses the covariates only to produce more homogeneous experimental material, thereby to reduce error.

Progress

Monitoring Armillaria Root Disease

Table 2.25 presents mortality data for 1986 through 1989 on the 36 plantation plot quarter-replicates. Mortality for each year is expressed as the percentage killed of the number of seedlings alive at the beginning of each year. Since root disease mortality was first noted in 1986, the only other cause of seedling loss has been the routine collection of seedlings for PMS and growth analysis. Striking differences in mortality among plots and plot quarter-replicates are apparent. Statistical analyses to date concerning these differences are described in the next subsection. In general, the rate of mortality increased between 1986 and 1987 (especially at the Control site), and again between 1987 and 1988 (most notably at the Antenna site). In 1989, the mortality rate declined slightly on about two-thirds of the quarter-replicates. This was probably due to the cool, moist spring experienced in 1989.

To date, 444 isolates collected since 1986 have been identified to 38 clones. These isolates represent 297 dead seedlings and 62, 43, 18, 23 and 1 isolates, respectively, derived from aspen, birch, maple, and oak and pine stumps (Table 2.26).

Some of the *Armillaria clones* active in the study plantations are not associated with red pine mortality. All of these clones which have been identified belong to the species Armillaria bulbosa (NABS VII). On the other hand, all identified clones which have killed seedlings belong to the species Armillaria ostoyae (NABS I). NABS VII is recognized to be a common saprotrophic species in northern hardwood stands, whereas NABS I is a widely distributed species, well known as an aggressive parasite of northern conifers.

Modelling Armillaria Root Disease Incidence

For convenience, the four quarter-replicates comprising each plantation plot replicate were combined to present the mortality/stump map data as Figures 2.8 - 2.24. Mortality has been mapped as the last digit of the year during which it occurred, whereas stumps are mapped as the first letter of their genus' common name. Numbers of stumps and their basal areas per hectare by species for each plantation plot quarter-replicate are presented in Table 2.27.

A systematic approach to regression model development is being taken. The relative importance of numbers of stumps vs. basal area as predictors of Armillaria root disease, by stump species and overall, on each plantation plot and overall, is being evaluated. Stump species may be presumed to differ qualitatively in their ability to support the activity of Armillaria spp., and aspen, birch, maple, oak and pine stumps

Table 2.25 Red pine seedling mortality due to Armillaria root disease on each of the 36 plantation plot quarter-replicates, from 1986 through 1989, presented both as the number of seedlings killed and the percentage killed of the number of seedlings alive at the beginning of each year.

Plot	Qtr Rep.	1986 No.	1986 %	1987 No.	1987 %	1988 No.	1988 %	1989 No.	1989 %	Total No.	Total %
Ground	1	0	0.00	1	0.57	3	1.88	2	1.32	6	3.77
	2	0	0.00	1	0.57	1	0.62	1	0.68	3	1.87
	3	0	0.00	2	1.15	2	1.25	1	0.67	5	3.07
	4	0	0.00	0	0.00	1	0.62	2	1.34	3	1.96
	5	0	0.00	2	1.25	4	2.76	0	0.00	6	4.01
	6	0	0.00	0	0.00	3	2.03	2	1.50	5	3.53
	7	0	0.00	5	3.13	3	2.10	5	3.97	13	9.20
	8	1	0.59	2	1.25	6	4.14	3	2.36	12	8.34
	9	0	0.00	11	6.75	12	8.63	6	5.00	29	20.38
	10	1	0.58	6	3.70	9	6.25	4	3.25	20	13.78
	11	0	0.00	1	0.61	0	0.00	0	0.00	1	0.61
	12	0	0.00	1	0.61	0	0.00	3	2.16	4	2.77
Antenna	13	2	1.07	4	2.30	5	3.16	4	2.74	15	9.27
	14	1	0.53	2	1.14	7	4.35	3	2.13	13	8.15
	15	3	1.60	1	0.57	4	2.50	1	0.68	9	5.35
	16	2	1.08	1	0.57	9	5.59	0	0.00	12	7.24
	17	0	0.00	1	0.78	0	0.00	4	3.81	5	4.59
	18	0	0.00	3	2.33	6	5.26	3	2.97	12	10.56
	19	0	0.00	0	0.00	1	0.85	9	8.82	10	9.67
	20	2	1.43	5	3.91	6	5.45	13	13.68	26	24.47
	21	0	0.00	3	1.68	10	6.13	4	2.80	17	10.61
	22	0	0.00	3	1.68	24	14.63	13	9.85	40	26.16
	23	0	0.00	5	2.79	10	6.21	11	7.53	26	16.53
	24	1	0.53	14	7.91	18	11.92	9	7.69	42	28.05
Control	25	5	1.98	15	6.25	16	7.51	11	5.98	47	21.72
	26	2	0.79	11	4.53	9	4.11	10	4.90	32	14.33
	27	0	0.00	6	2.45	17	7.49	7	3.47	30	13.41
	28	2	0.79	12	4.94	17	7.80	5	2.66	36	16.19
	29	0	0.00	8	2.85	7	2.68	10	4.07	25	9.59
	30	0	0.00	19	6.74	12	4.80	9	3.93	40	15.47
	31	3	1.03	11	3.94	5	1.95	10	4.22	29	11.14
	32	3	1.03	13	4.66	12	4.74	10	4.31	38	14.74
	33	1	0.35	10	3.66	11	4.38	10	4.35	32	12.74
	34	1	0.35	1	0.36	12	4.62	8	3.35	22	8.68
	35	1	0.35	4	1.46	6	2.33	4	1.68	15	5.82
	36	0	0.00	3	1.09	5	1.93	8	3.24	16	6.26

Table 2.26 Sources of the 444 Armillaria isolates grouped by clone to date.

Plot	Clone	Species	No. Seedlings Killed	Stump Species: Aspen	Birch	Maple	Oak	Pine	Total
Ground	a		1	0	1	0	0	0	2
	b		3	1	1	0	0	0	5
	c		0	3	1	1	0	0	5
	d		6	3	2	0	0	0	11
	e		1	0	0	0	0	0	1
	f		12	3	0	1	0	0	16
	g		0	5	1	0	2	0	8
	h		1	0	0	0	0	0	1
	i		24	13	2	3	0	0	42
	j		3	0	0	4	0	0	7
	k		1	1	0	0	0	0	2
	l		0	1	0	0	0	0	1
	n		1	1	0	0	0	0	2
	p		1	0	0	0	0	0	1
Antenna	a		0	7	3	1	0	0	11
	b		18	9	1	1	0	0	29
	c		5	3	0	0	0	0	8
	d		6	1	1	0	0	0	8
	e		5	2	0	0	0	0	7
	f		0	2	2	0	0	0	4
	g		27	1	1	0	1	0	30
	h		16	0	3	0	0	1	20
	i		4	1	1	0	0	0	6
Control	a	VII	0	2	13	5	11	0	31
	b	I	24	0	0	1	1	0	26
	c	VII	0	0	0	0	4	0	4
	d		11	0	1	0	0	0	12
	e		3	0	0	0	1	0	4
	f		24	0	0	0	1	0	25
	g		2	0	0	0	0	0	2
	h	I	1	1	0	0	0	0	2
	i		17	0	2	0	0	0	19
	j		3	0	0	0	0	0	3
	k		0	0	1	0	0	0	1
	l		1	0	0	0	0	0	1
	m	I	30	1	6	1	2	0	40
	n		1	1	0	0	0	0	2
	o		45	0	0	0	0	0	45

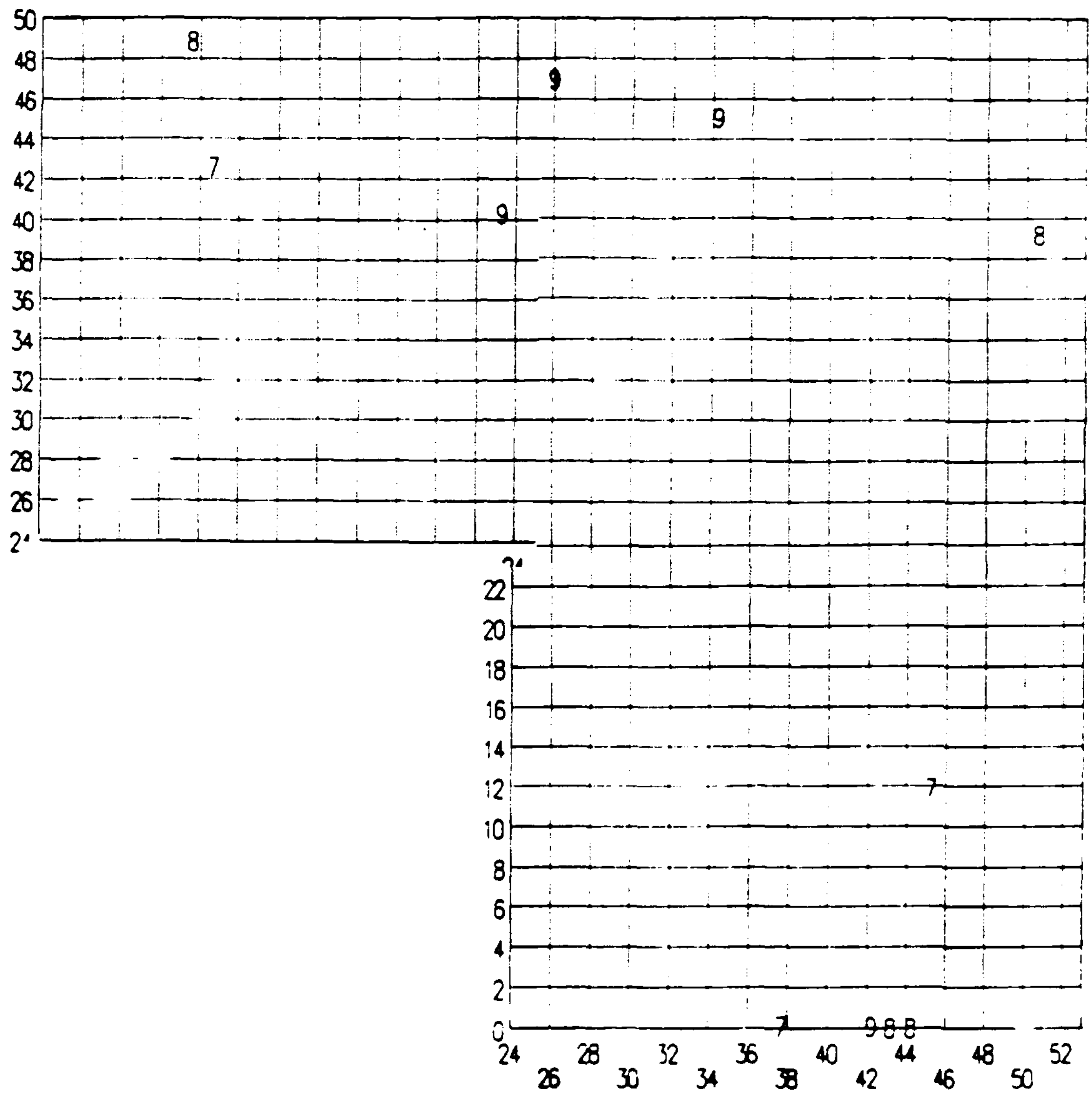


Figure 2.8. Red pine seedling mortality on Ground plantation quarter-replicates 1 - 4 (replicate 1), mapped as the last digit of the year during which they died (scale is in meters).

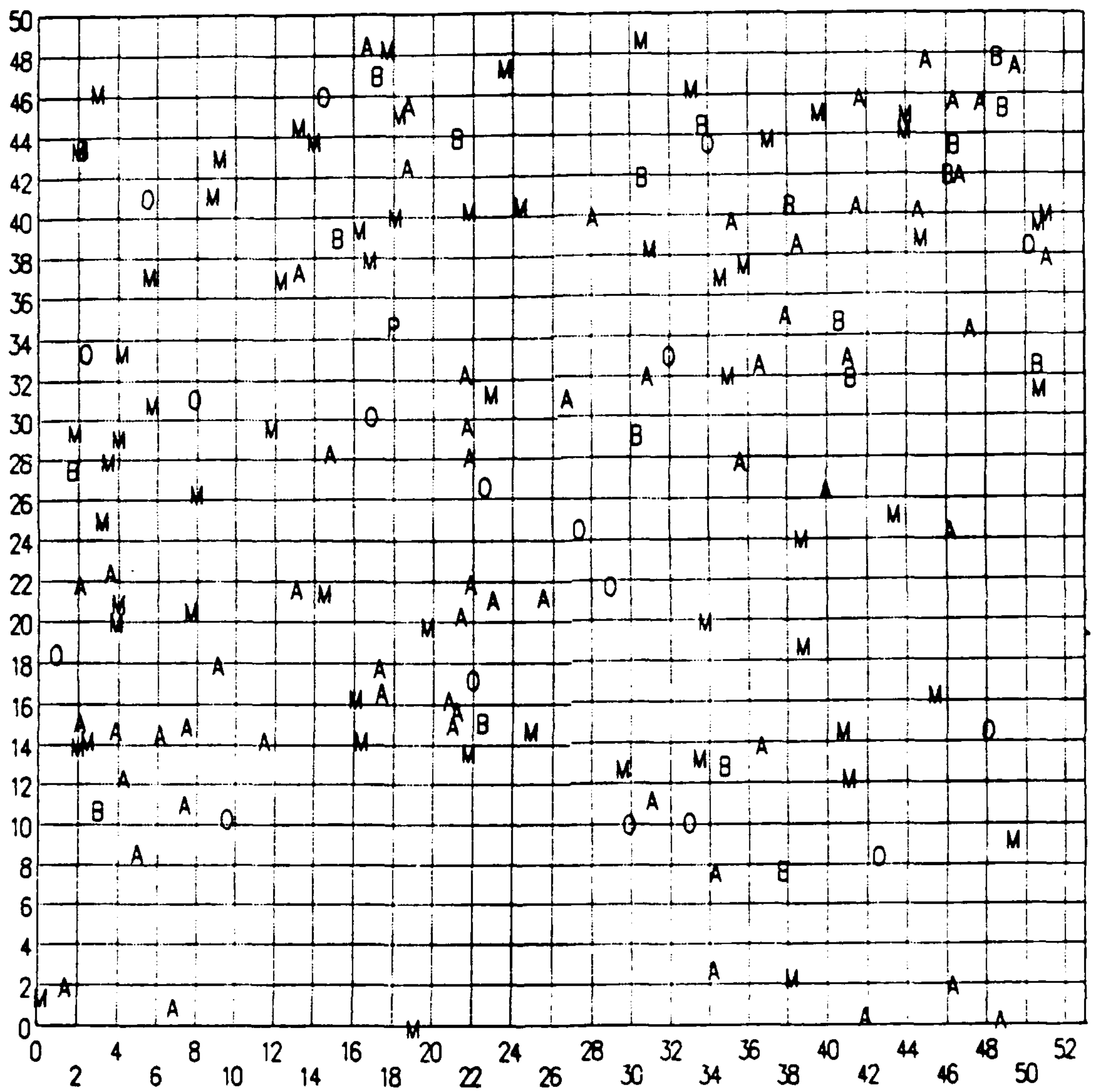


Figure 2.9. Stumps on Ground plantation quarter-replicates 1 - 4 (replicate 1), mapped as the first letter of the genus common name (Aspen, Birch, Maple, Oak, Pine; (scale in meters).

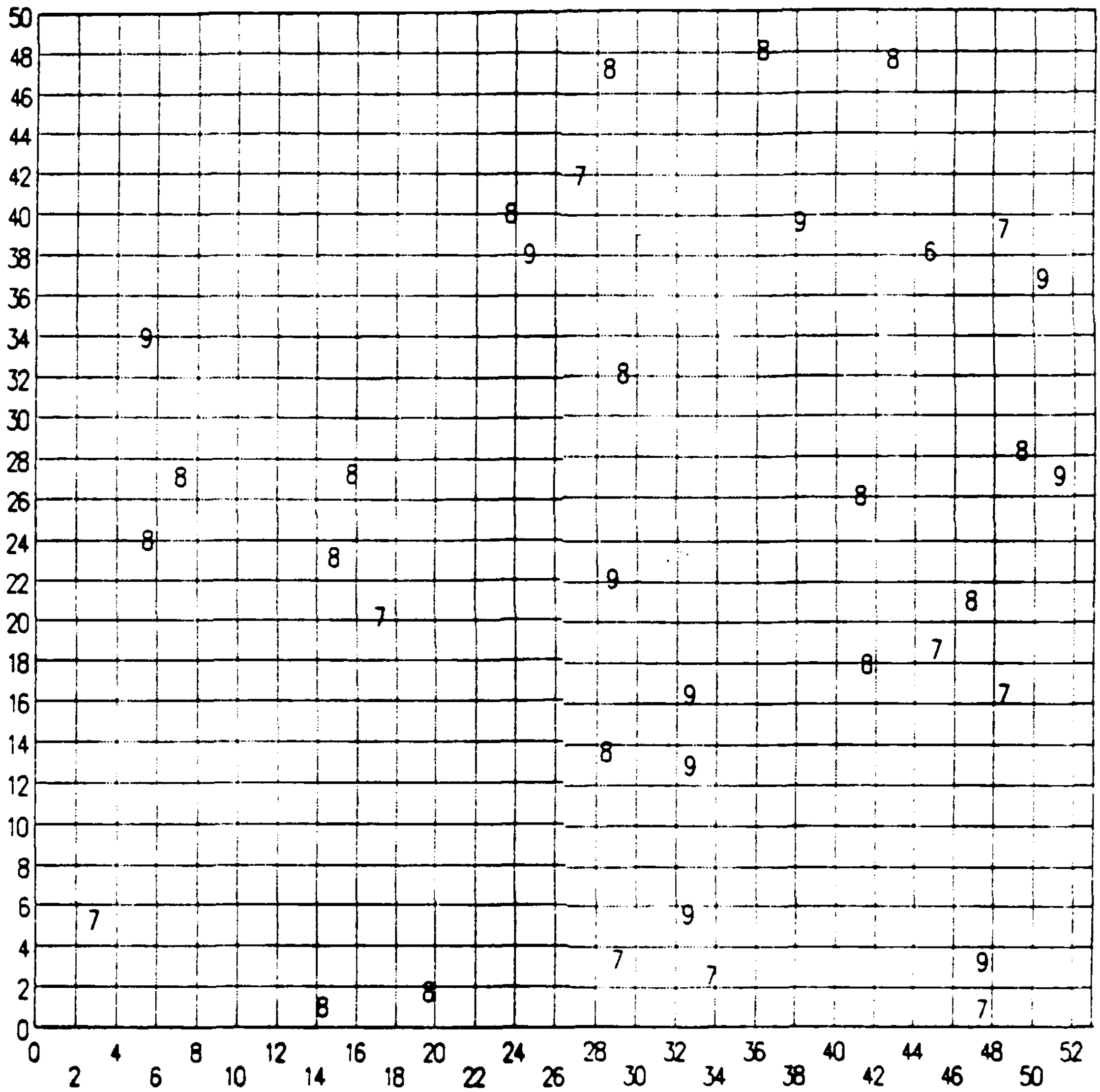


Figure 2.10. Red pine seedling mortality on Ground plantation quarter-replicates 5 - 8 (replicate 2), mapped as the last digit of the year during which they died (scale is in meters).

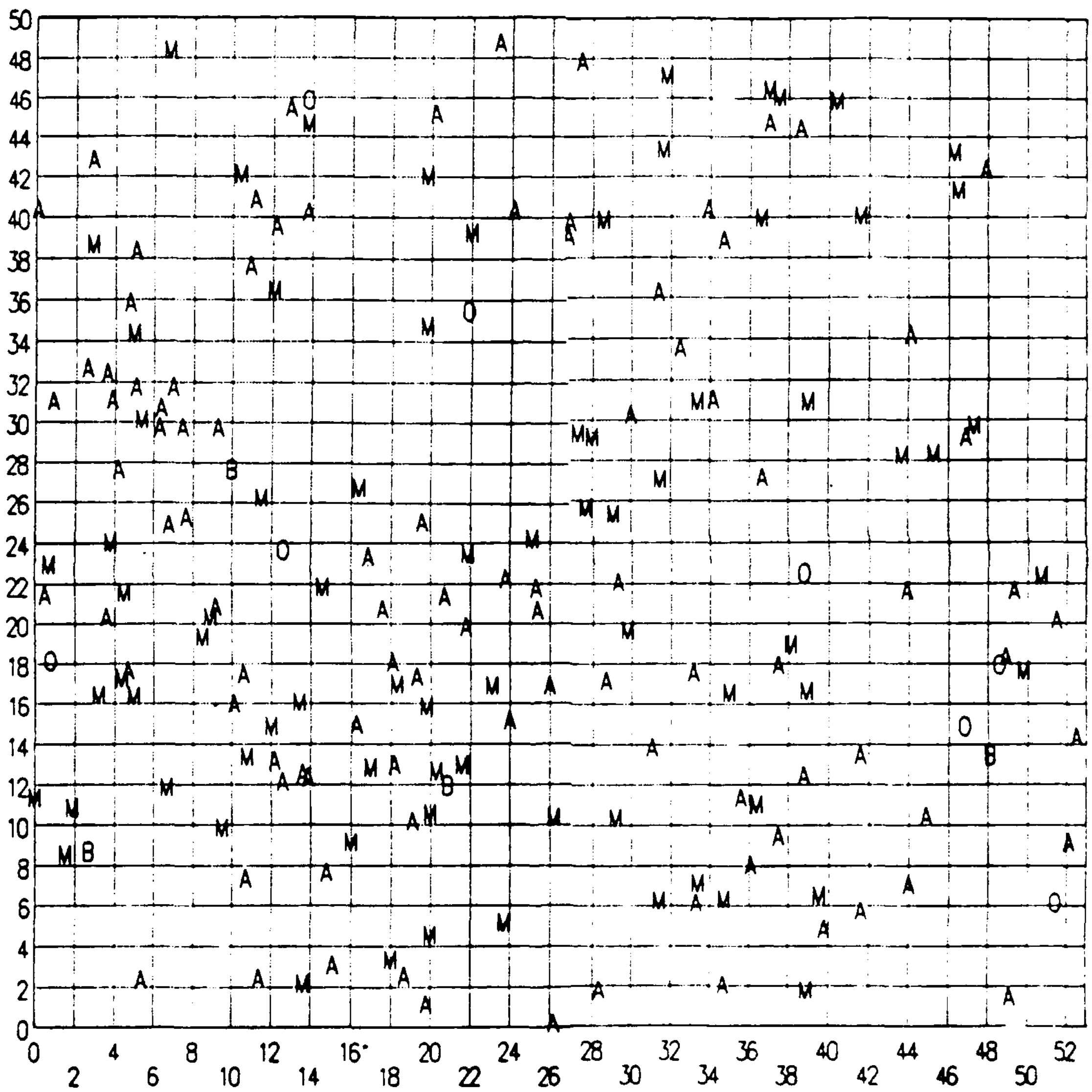
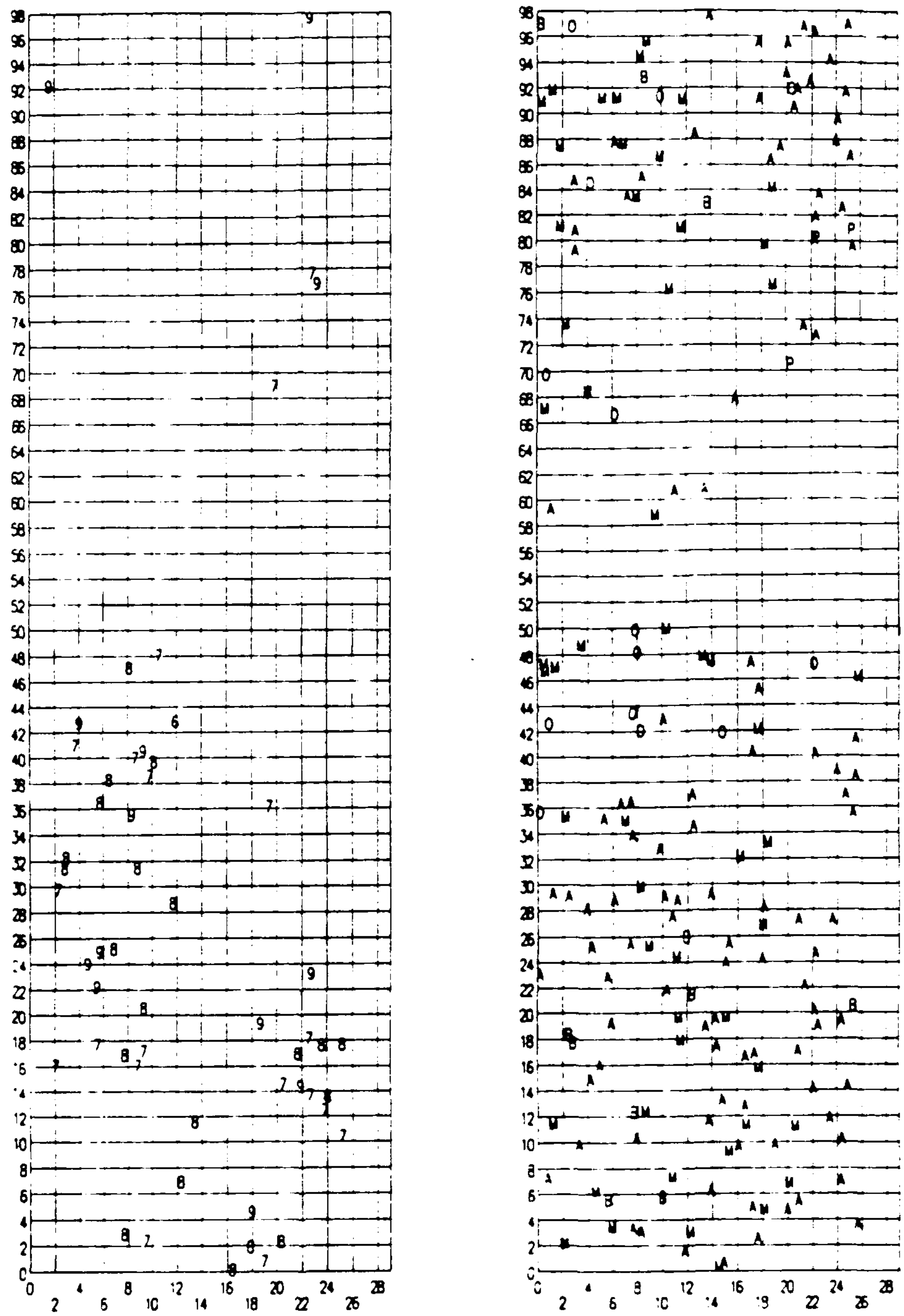


Figure 2.11. Stumps on Ground plantation quarter-replicates 5 - 8 (replicate 2), mapped as the first letter of the genus common name (Aspen, Birch, Maple, Oak, Pine; (scale in meters).



(a) (b)

Figure 2.12. Red pine seedling mortality (a) and stumps (b) on Ground plantation quarter-replicates 9 - 12 (replicate 3), mapped as the last digic of the year of mortality or the first letter of the stump genus common name (Aspen, Birch, Maple, Oak, Pine; (scale in meters).

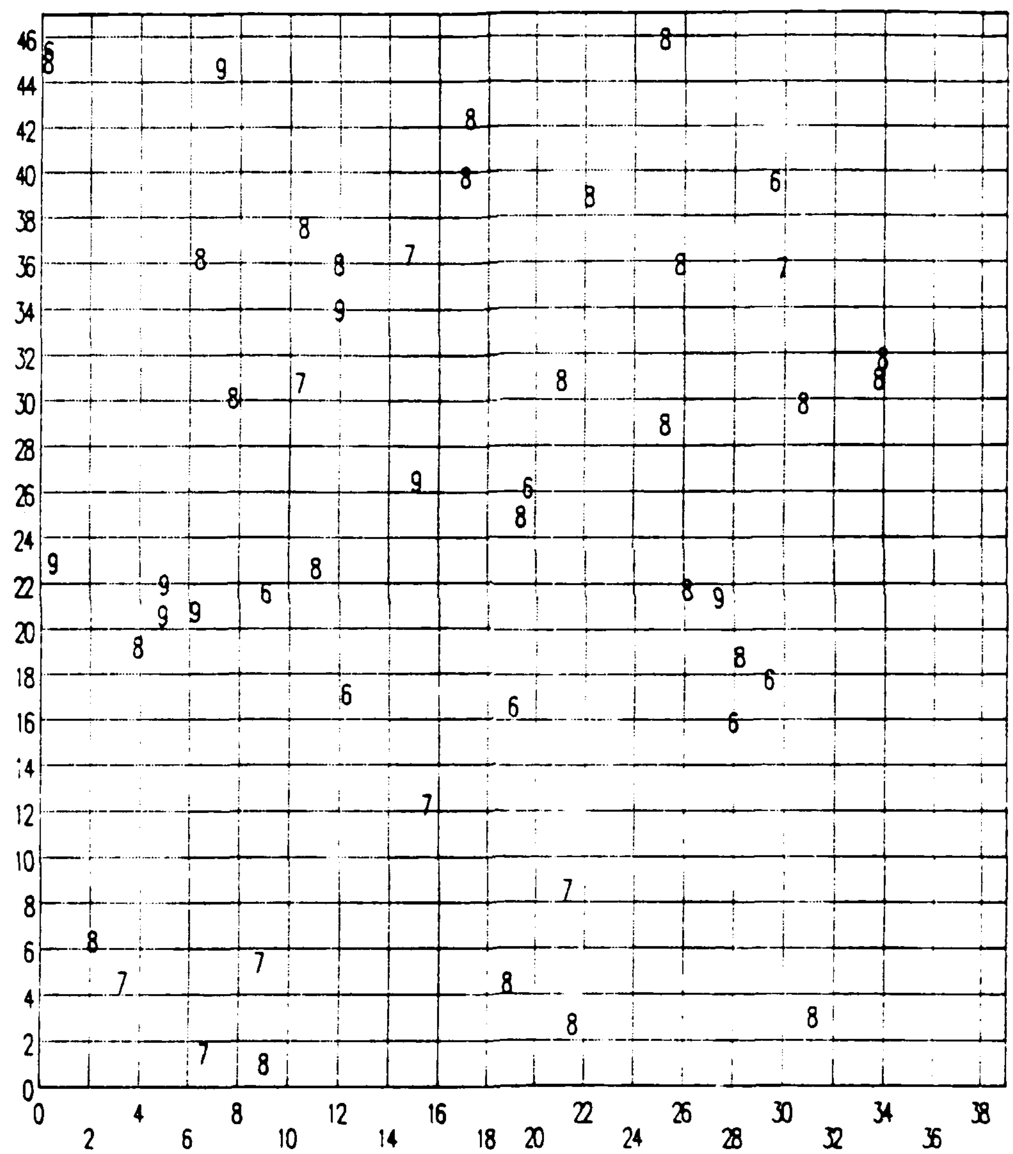


Figure 2.13. Red pine seedling mortality on Antenna plantation quarter-replicates 13 - 16 (replicate 1), mapped as the last digit of the year during which they died (scale is in meters).

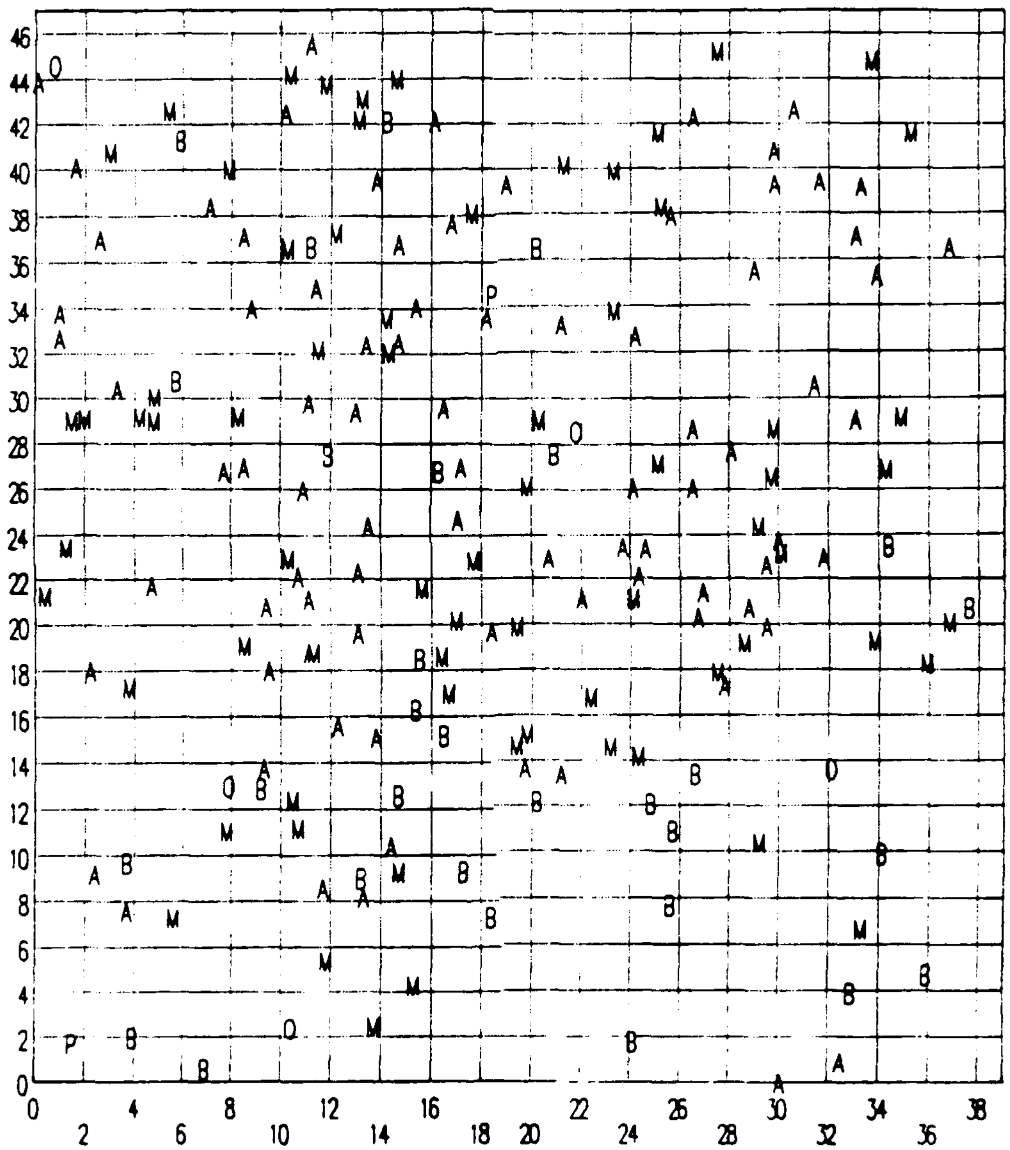


Figure 2.14. Stumps on Antenna plantation quarter-replicates 13 - 16 (replicate 1), mapped as the first letter of the genus common name (Aspen, Birch, Maple, Oak, _Pine; (scale in meters).

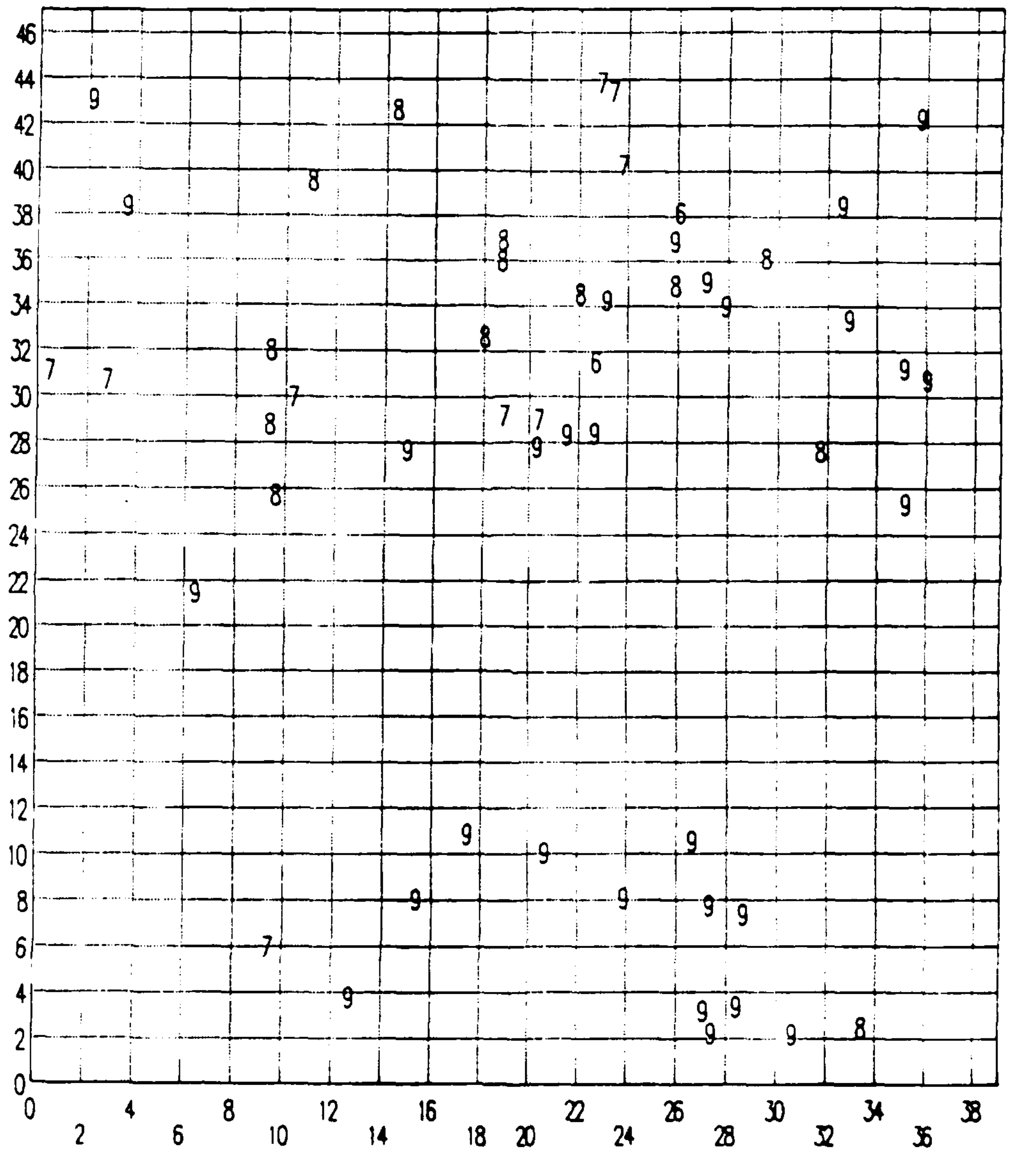


Figure 2.15. Red pine seedling mortality on Antenna plantation quarter-replicates 17 - 20 (replicate 2), mapped as the last digit of the year during which they died (scale is in meters).

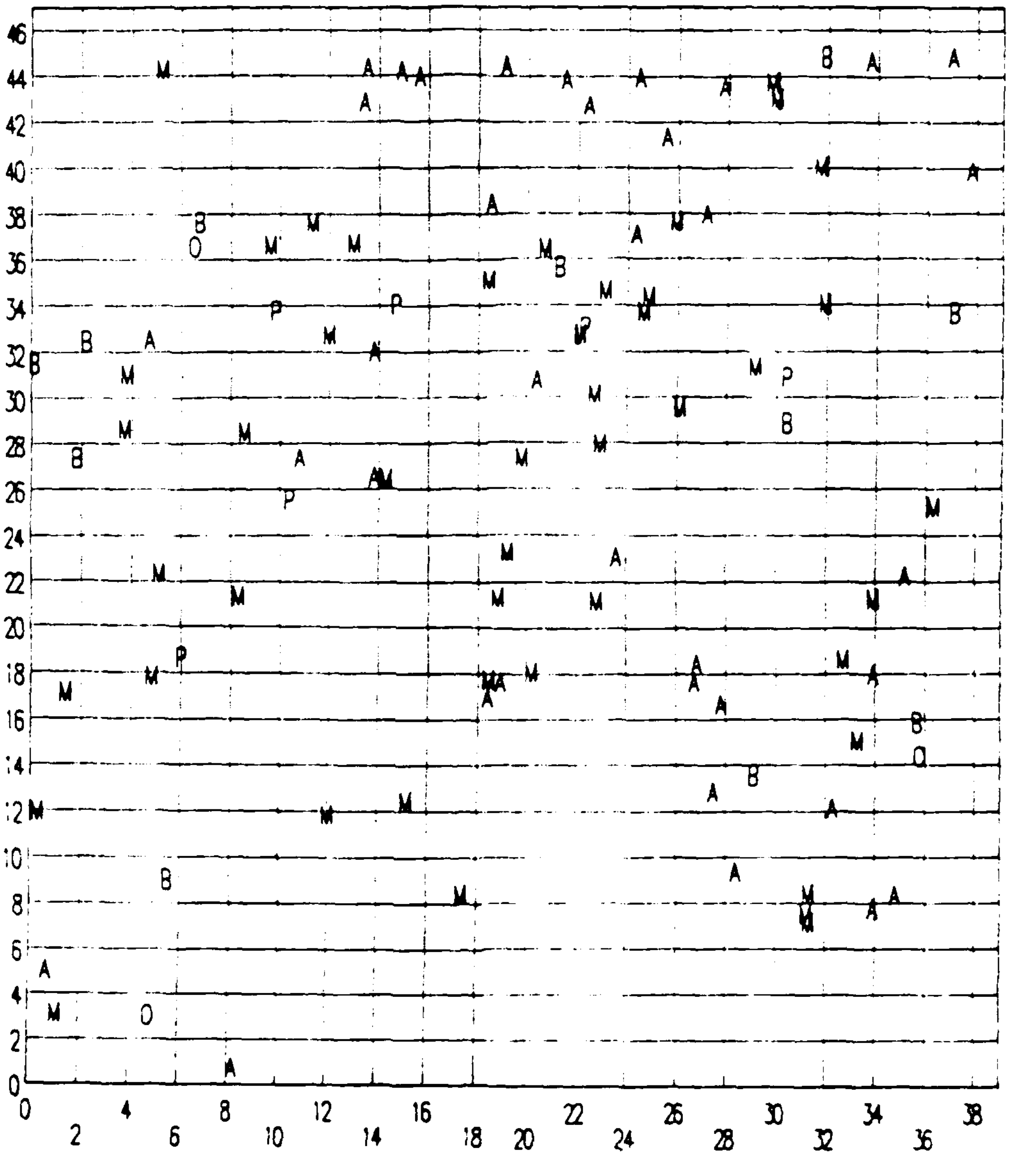


Figure 2.16. Stumps on Ground plantation quarter-replicates 17 - 20 (replicate 2), mapped as the first letter of the genus common name (Aspen, Birch, Maple, Oak, _Pine; (scale in meters).

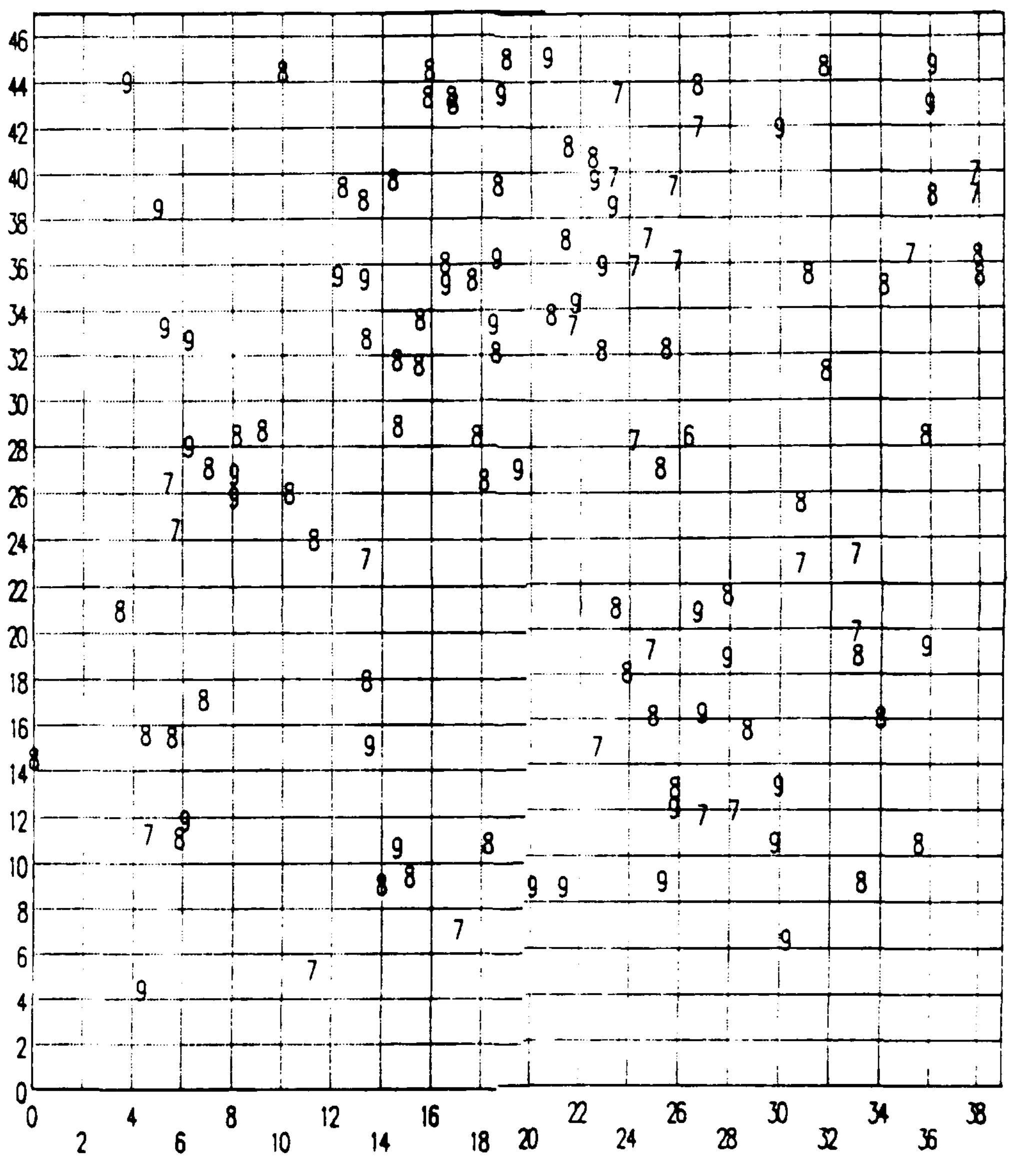


Figure 2.17. Red pine seedling mortality on Antenna plantation quarter-replicates 21 - 24 (replicate 3), mapped as the last digit of the year during which they died (scale is in meters).

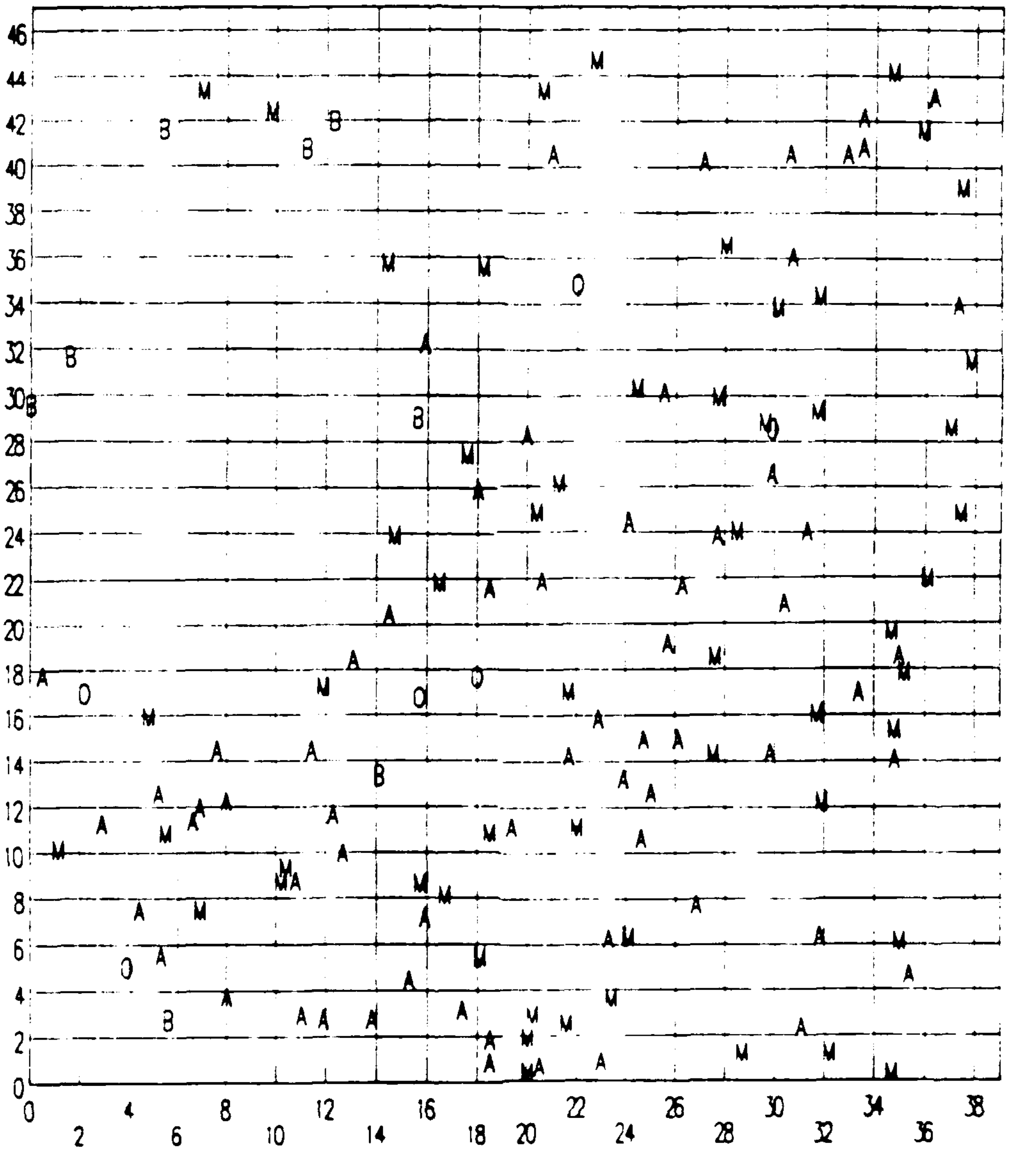


Figure 2.18. Stumps on Antenna plantation quarter-replicates 21 - 24 (replicate 3), mapped as the first letter of the genus common name (Aspen, Birch, Maple, Oak, Pine; (scale in meters).

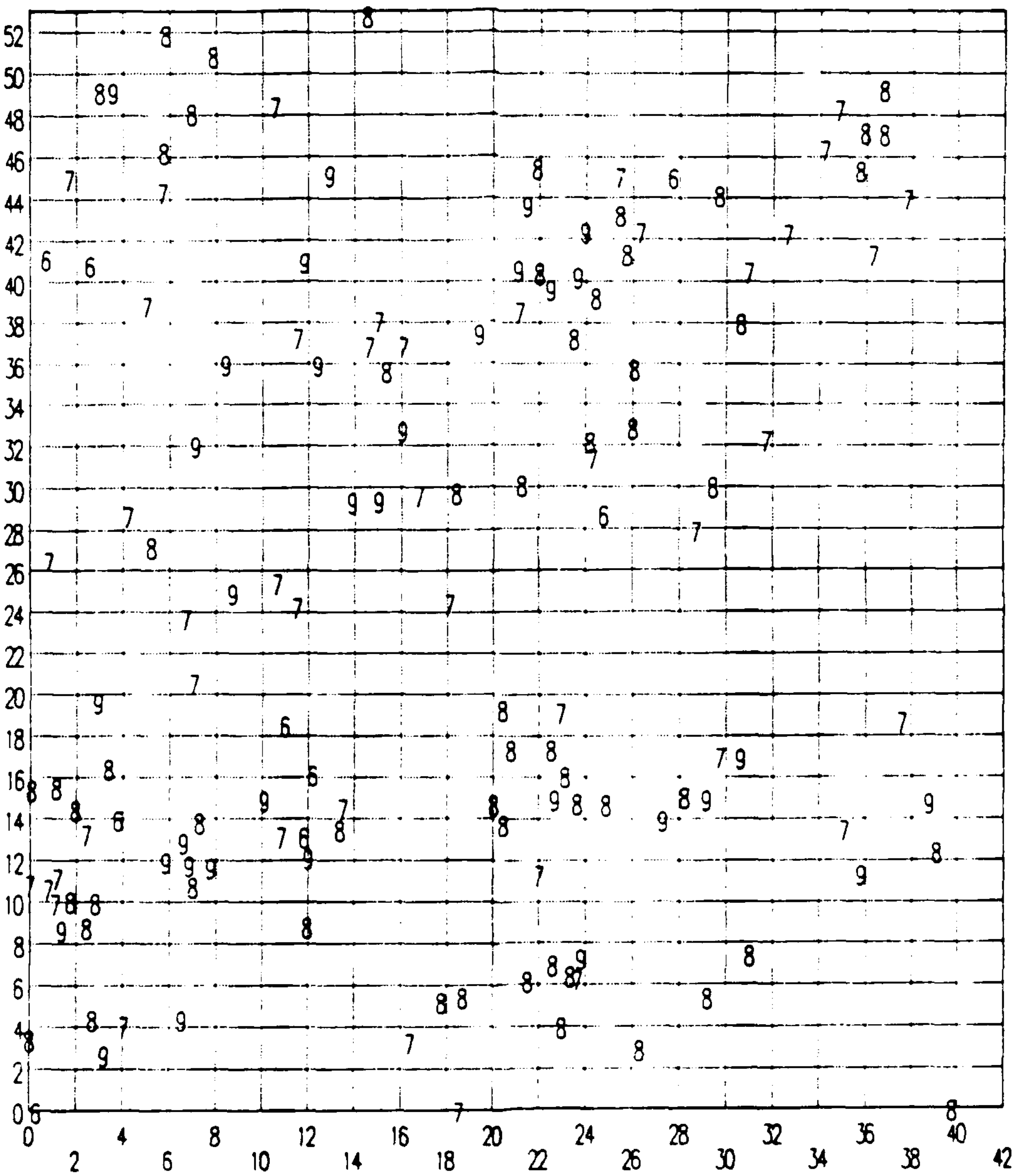


Figure 2.19. Red pine seedling mortality on Control plantation quarter-replicates 25 - 28 (replicate 1), mapped as the last digit of the year during which they died (scale is in meters).

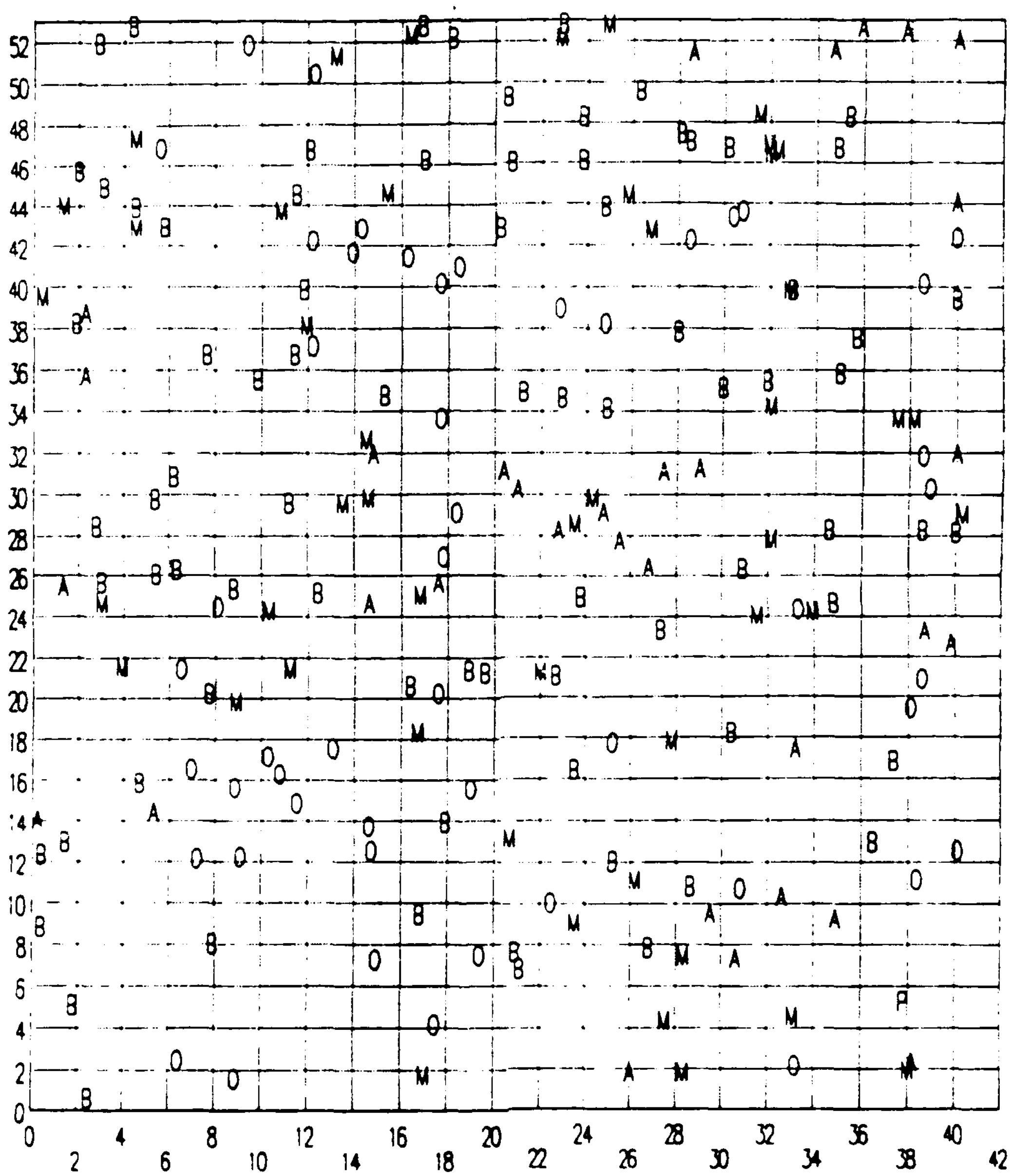


Figure 2.20. Stumps on Control plantation quarter-replicates 25 - 28 (replicate 1), mapped as the first letter of the genus common name (Aspen, Birch, Maple, Oak, Pine; (scale in meters).

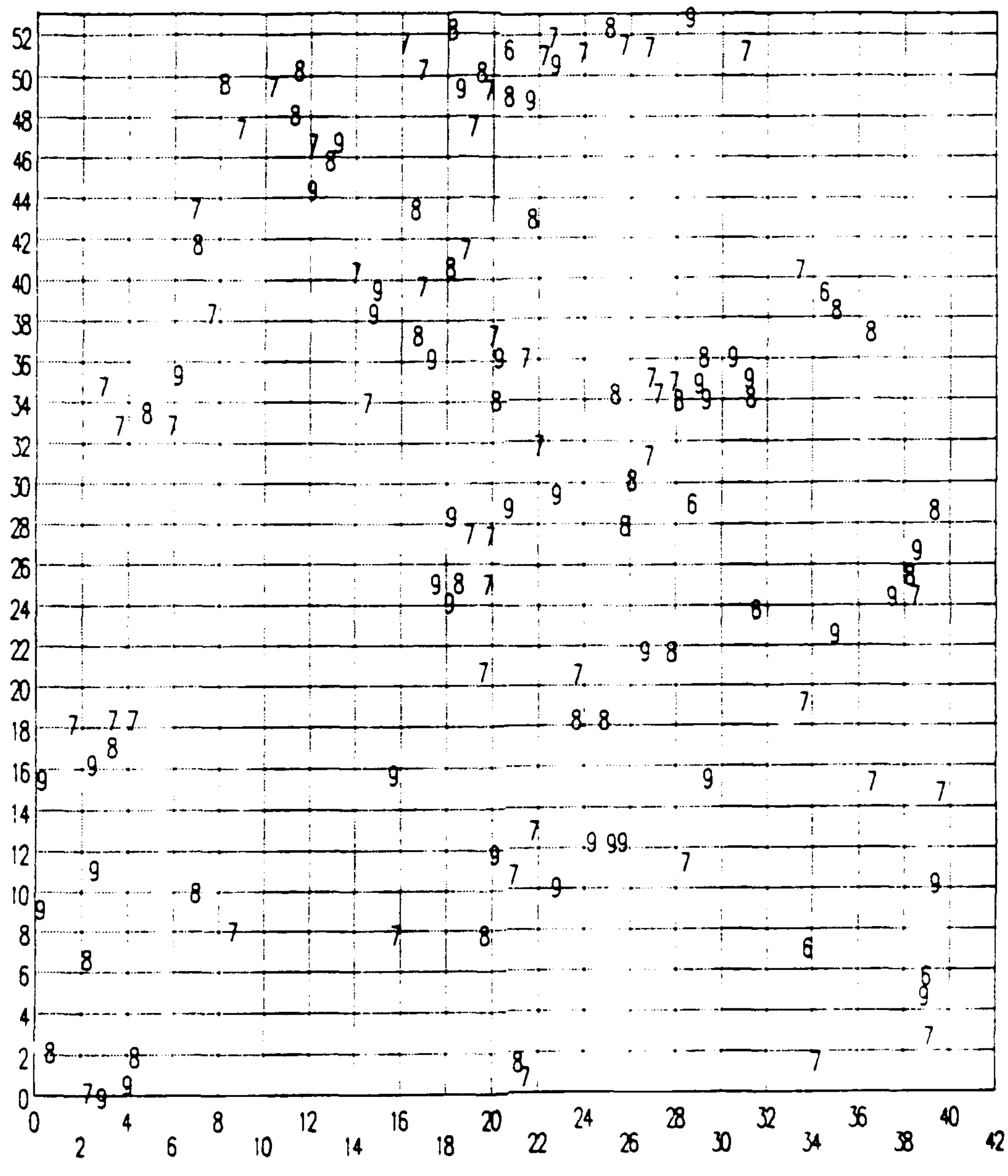


Figure 2.21. Red pine seedling mortality on Control plantation quarter-replicates 29 - 32 (replicate 2), mapped as the last digit of the year during which they died (scale is in meters).

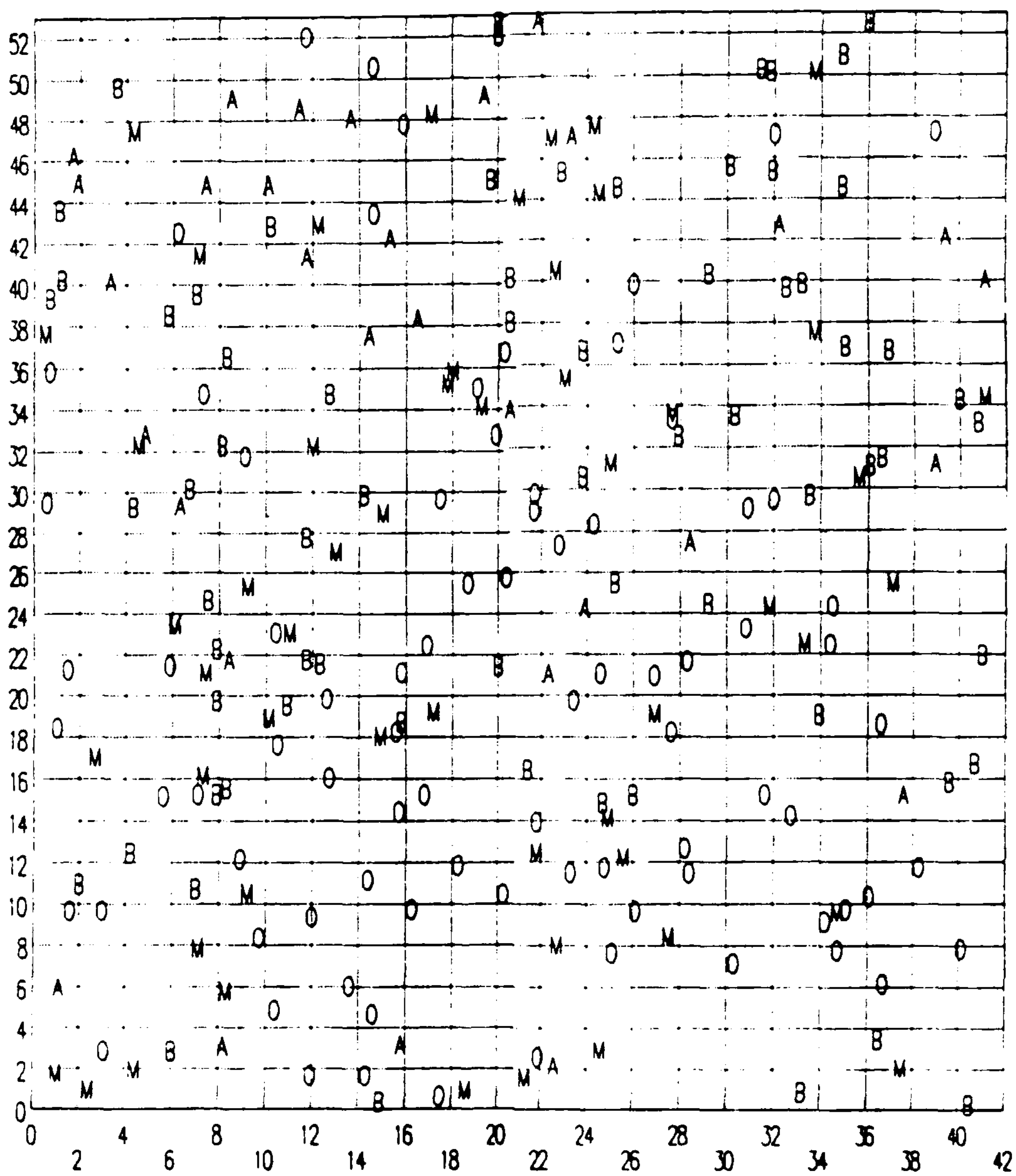


Figure 2.22. Stumps on Control plantation quarter-replicates 29 - 32 (replicate 2), mapped as the first letter of the genus common name (Aspen, Birch, Maple, Oak, _Pine; (scale in meters).

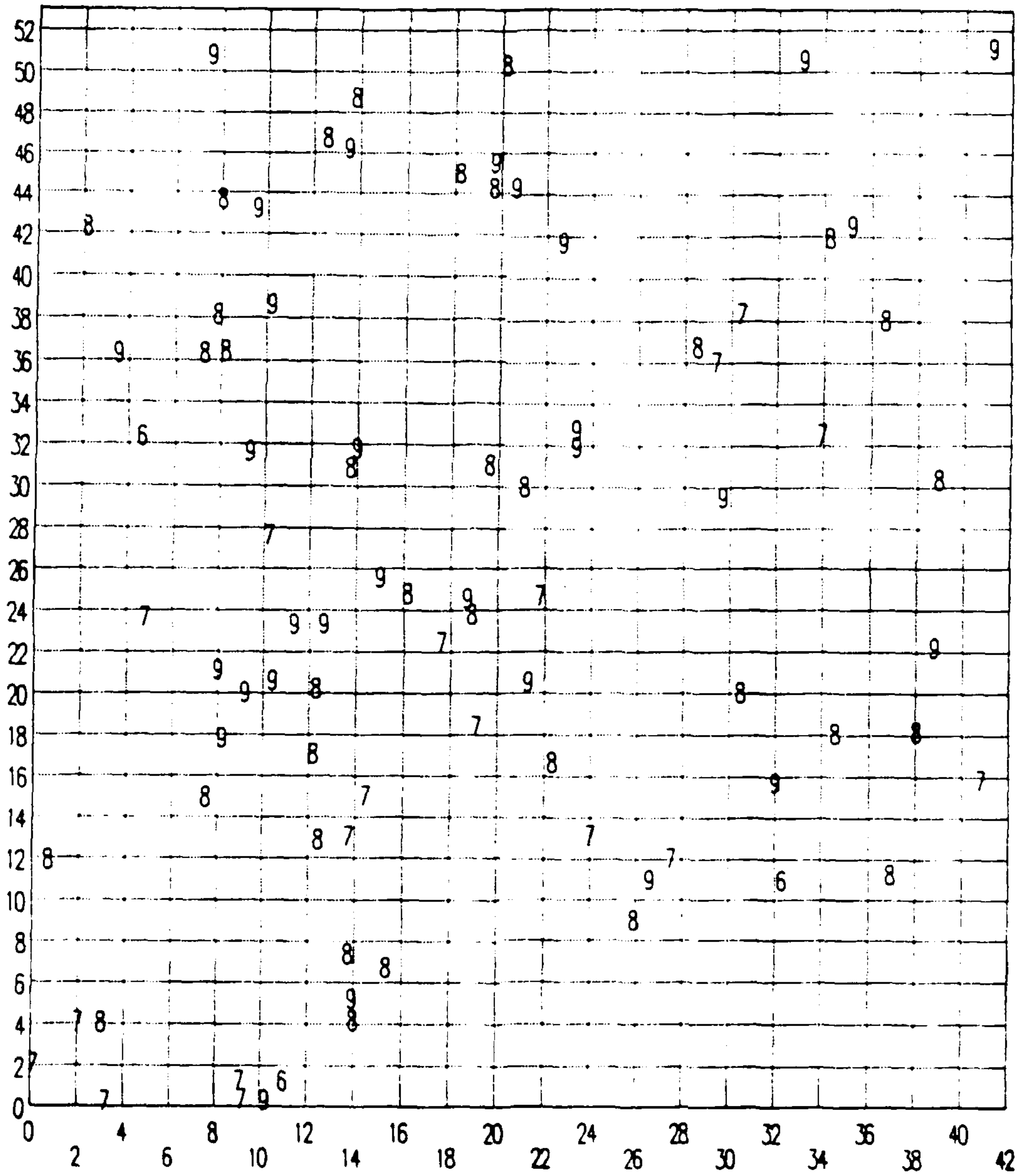


Figure 2.23. Red pine seedling mortality on Control plantation quarter-replicates 33 - 36 (replicate 3), mapped as the last digit of the year during which they died (scale is in meters).

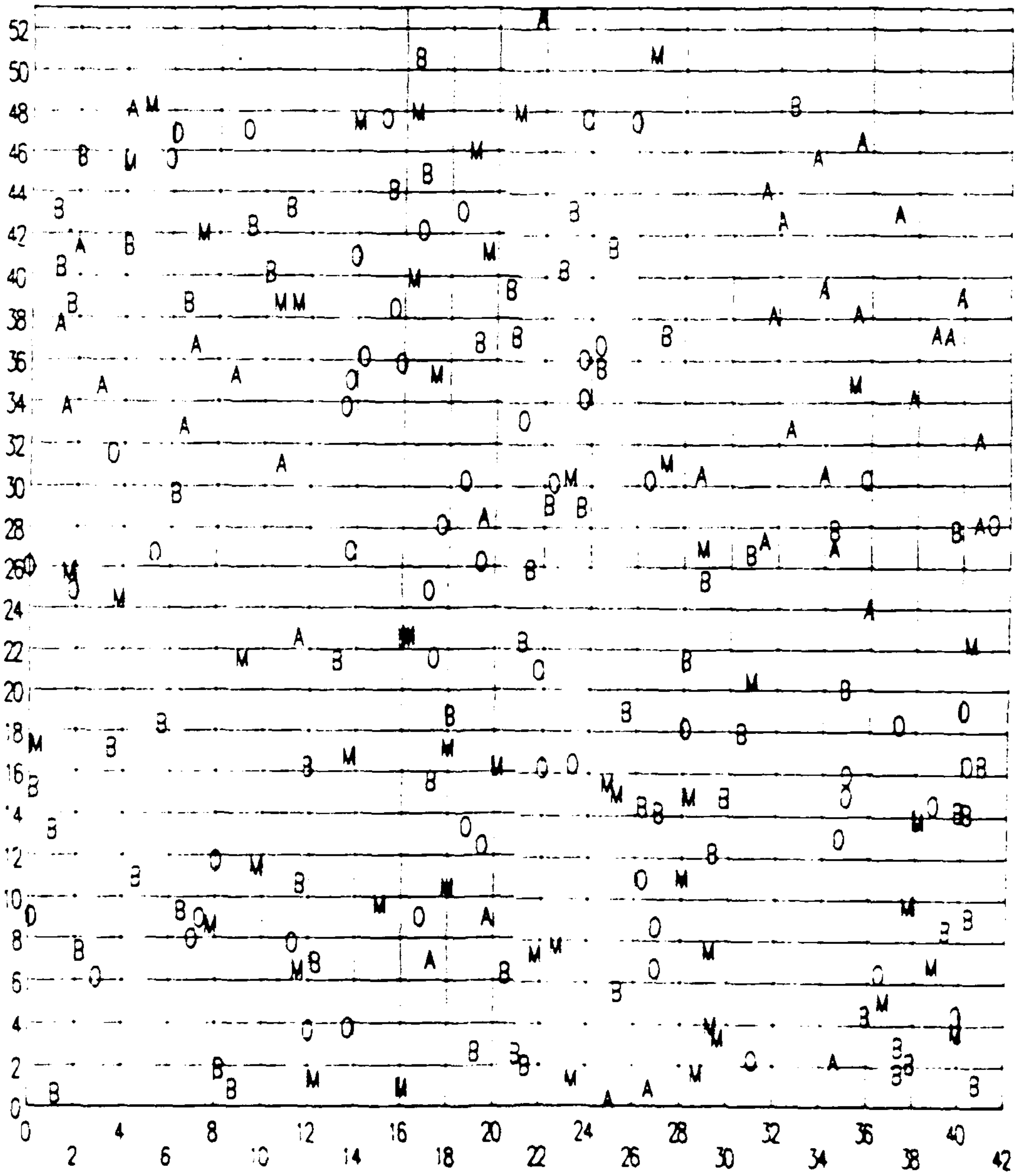


Figure 2.24. Stumps on Control plantation quarter-replicates 33 - 36 (replicate 3), mapped as the first letter of the genus common name (Aspen, Birch, Maple, Oak, _Pine; (scale in meters).

Table 2.27 Stump numbers and basal area (m^2) per hectare by species for each plantation plot quarter-replicate.

Plot	Qtr. Rep.	Aspen No.	Aspen BA	Birch No.	Birch BA	Maple No.	Maple BA	Oak No.	Oak BA	Pine No.	Pine BA	Total No.	Total BA
Grnd.	1	365	17	32	1	206	11	48	7	0	0	651	35
	2	127	6	79	3	397	27	95	38	16	2	714	76
	3	127	5	32	2	159	13	79	19	0	0	397	40
	4	317	17	175	9	238	17	63	21	0	0	794	64
	5	500	18	31	3	500	32	31	7	0	0	1062	60
	6	406	19	16	0	188	22	31	16	0	0	641	57
	7	375	14	16	1	203	26	62	9	0	0	656	50
	8	234	12	0	0	312	38	0	0	0	0	547	50
	9	651	27	111	5	270	23	0	0	0	0	1032	55
	10	508	25	16	0	254	10	111	34	0	0	889	69
	11	79	8	0	0	63	4	48	18	16	1	206	31
	12	492	18	48	5	286	28	63	16	32	1	921	67
Ant.	13	409	13	250	38	432	19	45	1	23	1	1159	73
	14	659	29	136	18	477	11	23	1	23	3	1318	61
	15	273	12	227	61	318	12	23	1	0	0	841	86
	16	581	30	70	6	395	19	23	7	0	0	1070	63
	17	48	2	24	3	238	48	24	2	24	2	357	56
	18	209	11	93	12	233	15	23	6	70	10	628	54
	19	293	25	49	1	220	8	24	2	0	0	585	35
	20	310	15	95	23	405	16	0	0	48	10	857	64
	21	581	26	47	9	279	17	93	12	0	0	1000	64
	22	47	4	140	27	140	14	0	0	0	0	326	44
	23	535	27	0	0	465	24	0	0	0	0	1000	51
	24	349	18	0	0	419	38	47	2	0	0	814	58
Ctl.	25	94	4	340	20	151	6	358	35	0	0	943	64
	26	57	2	396	33	226	6	245	18	0	0	925	58
	27	170	12	245	14	226	6	170	17	19	3	830	52
	28	283	9	509	35	302	16	170	12	0	0	1264	72
	29	74	4	278	6	296	6	593	44	0	0	1241	59
	30	278	8	315	40	222	5	241	25	0	0	1056	78
	31	74	3	222	28	241	4	500	36	0	0	1037	71
	32	148	6	463	44	222	9	204	20	0	0	1037	78
	33	55	3	345	48	291	7	291	19	0	0	982	76
	34	182	8	273	33	200	8	309	26	0	0	964	75
	35	73	3	436	27	327	6	309	23	0	0	1145	61
	36	364	16	218	15	109	3	182	12	0	0	873	47

occur in various mixtures on the 36 quarter-replicates. Numbers and basal areas of stumps by species have been further categorized as sprouting or non-sprouting, on all three plantation plots in 1988, and on the control plantation plot again in 1989. It was not possible to evaluate sprouting on the Ground or Antenna plantation plots in 1989, due to mechanical sprout removal earlier in the year (unnecessary at the Control plantation plot). Sprouting will be evaluated again in 1990, on all three plantation plots. Categorization of stumps as either sprouting or non-sprouting is useful, because non-sprouting stumps are likely to support greater Armillaria activity. Birch stump distribution was the most useful single variable tested in 1987, for predicting red pine seedling mortality (Bruhn et al. 1989). The apparent explanation for this focused on the relative sprouting vigor of the hardwood species involved. Birch root systems might be expected to decline more quickly following clearcutting than those of aspen, maple and oak, which are more vigorous sprouters than birch. As the most rapidly declining stumps on the plantation plots, birch stumps would represent the majority of the available foodbases for Armillaria at the time. We expected the relationship between mortality level and birch stump distribution to change in the future, as other species of stumps decline to the point of becoming important Armillaria foodbases. Analysis underway indicates that this has happened.

Other independent variables included in the analysis this year are 1) percent rock content by volume, for three strata (0-10 cm, 10-30 cm, and 30-50 cm), with a single sample value representing each plot replicate (four quarter-replicates), 2) bulk density of the soil fraction <2 mm, for the same three strata and samples, 3) mean seedling height at the end of each year on each quarter-replicate, for surviving "permanent" measurement seedlings, and 4) mean seedling terminal bud length at the end of each year on each quarter-replicate, for the same seedling sample. Results of the completed analysis will be presented in the 1990 annual report.

ELEMENT 3: PHENOPHASE DESCRIPTION AND DOCUMENTATION

Starflower, *Trientalis borealis* Raf., is an important herbaceous species both on the control site and the ELF antenna site. Because phenophases of starflower have been well documented in northern Wisconsin (Anderson and Loucks, 1973) and in Canada (Helenurm and Barrett, 1987), changes in starflower's phenological responses with increasing ELF fields can be evaluated with some reliability and comparability. Changes in phenological characteristics can provide information on an ecosystem's response to many types of disturbances. Phenological events, such as timing of stem elongation, bud break, leaf expansion, flowering, fruiting and leaf senescence have been used to monitor and assess a plant's response to climatic and edaphic factors. Morphological characteristics, such as leaf area, stem length, number of buds, number of leaves, number of flowers, and number of fruit also provide necessary information on a plant's response to climatic and edaphic factors. This information can then be used to assess the overall vigor of that plant to withstand major perturbations. It is important, therefore, to monitor the phenological events and morphological characteristics of herbaceous species when evaluating the response of an ecosystem to ELF fields.

To assess the effects of ELF fields on *Trientalis borealis*, the objectives of this element are to: 1) describe and document specific changes in phenological events and in the morphological characteristics of *Trientalis borealis* prior to and during operational use of the ELF antenna and 2) use these data to test hypotheses of possible changes in physiological and phenological processes due to ELF fields.

The main null hypothesis to be tested each year is:
H_O: There is no difference in the onset of flowering and the timing of leaf expansion of *Trientalis borealis* between the antenna and the control sites within a year.

The hypothesis to be tested over all years is:
H_O: There is no difference in the onset of flowering and the timing of leaf expansion of *Trientalis borealis* before and after the ELF antenna becomes operational.

Morphological characteristics (number of buds, number of flowers, number of fruit, and maximum leaf area) will also be analyzed within the context of these hypotheses. Ambient characteristics within each year will be tested to determine if they explain significant differences among years and sites for the phenological characteristics of leaf expansion, leaf size (area, length, and width), and for stem length.

Sampling and Data Collection

During the 1989 field season, data were collected at the antenna and control sites between May 11 and August 25. Each site was sampled twice a week from May 11 until June 22 to delineate flowering periods and leaf expansion with greater precision. After full leaf expansion and flower development, each site was sampled once a week until August 25. Parameters measured per plant for each observation period included stem length, length and width of the largest leaf, number of leaves, number of buds, number of flowers, number of fruit, number of yellow leaves (leaves senescing), and number of brown leaves. To ensure an adequate representation of starflower phenophases, a minimum sample size of 200 individual plants per site was maintained for each observation period during leaf expansion, bud formation, and flowering. To achieve this goal, a single transect line was run and subsequently divided into permanent 1 m^2 subplots. Individual plants within each subplot were then numbered and tagged until a normal distribution of mean stem length was attained. Stem length was used as the response variable for this determination because it is a prime indicator of a herbaceous plant's potential sexual productivity. A normal distribution of stem length insures an adequate representation of the population for analysis of variance techniques. The number of meter square subplots required to obtain a minimum sample size of 200 plants varied between the antenna and control site and among weeks sampled. To reduce bias in choosing the 200th individual, all individual plants were tagged and measured in the subplot where the 200th plant occurred, hence sample size was unequal across sampling days. This sampling method was maintained for each individual plant until tagged individuals began to die or were eaten. Thereafter, observations were taken only on the remaining tagged individuals. Maximum leaf area was estimated for each plant by 1) taking the largest leaves on 15 randomly sampled plants off the herbaceous reserves at each observation period in 1986, 1987, 1988, and 1989, 2) measuring leaf length, leaf width and leaf area on these 15 samples, and 3) developing regression equations for leaf area (dependent variable) using leaf length and width as independent variables.

As with last year, a separate analysis was run on the effects of handling individual plants. This year, three permanent plots (1 m^2) were established on each site approximately 1 m from the sampled transect at varying distances along the transect. All plants within each "unhandled" plot were measured on one occasion (June 22) and compared to "handled" plots adjacent to the "unhandled" plots. Care was taken to ensure the least amount of handling occurred to plants on the "unhandled" plots. The number of "handled" plots sampled was based on the sample size (number of starflower plants) of the "unhandled" plots, so that equal sample sizes could be used for the analyses. Two hundred starflower plants were measured on the "unhandled" plots and

197 plants were measured on the "handled" plots. Three morphological characteristics (stem length, leaf length, and leaf width) were used as response variables. Results indicated that there were no significant decreases ($p > 0.20$) in stem length, leaf length, and leaf width of "handled" plants (Table 3.1) on both the control and the antenna site for all the response variables. As with prior years on the "handled" plots, significant differences ($p < 0.04$) in stem length, leaf length, and leaf width were determined between the control and the antenna sites. No significant interactions ($p > 0.06$) between handled/unhandled plots and sites were determined. Analysis of handling effects on plant size will continue next year.

Progress

Phenological characteristics

In 1989, stem expansion on the antenna site began one week earlier than stem expansion on the control site, while leaf expansion occurred at similar times on both sites. Bud formation on the control site began at the same time (May 11) as bud formation on the antenna site (Figure 3.1E). Flowering on the antenna site began 4 days earlier (May 18) than flowering on the control site (Figure 3.2E). As with bud formation, fruiting occurred at the same time on the control site as fruiting on the antenna site (Figures 3.3I and 3.3J). Leaf senescence (yellowing leaves) began at the same time (June 12) on the antenna site as on the control site (Figures 3.4I and 3.4J) while the occurrence of dead leaves (brown leaves) began 4 days earlier (June 15) on the antenna site than on the control site (Figures 3.5I and 3.5J). Similar relationships occurred either in the 1988, 1987, 1986, or 1985 growing seasons indicating that the small ELF fields that were present during the 1989 growing season had no distinguishable effect on the timing of starflower's phenological events.

In observing the phenological events of flowering and fruiting on both sites, each event began when the previous event was at its maximum except for flowering on the antenna site (Figure 3.6I and 3.6J). The proportion of plants flowering was significantly lower on the control site (<12%) than in previous years (>20%) indicating that there is some phenological and morphological change occurring on this site. This change may be due to climate, handling, or to interactions among these factors. Significant differences in the number of plants flowering were not detected on the antenna site. Significant differences in the percent of plants with buds were detected this year. Reasons for this are unclear since the amount of plants flowering was not different from last year. At this time, differences in the relationships of phenological events between the antenna and

Figure 3.1: Relative frequency for number of plants with one or more buds by sampling date on the control and the antenna sites for 1985 (A), 1986 (B), 1987 (C), 1988 (D), and 1989 (E).

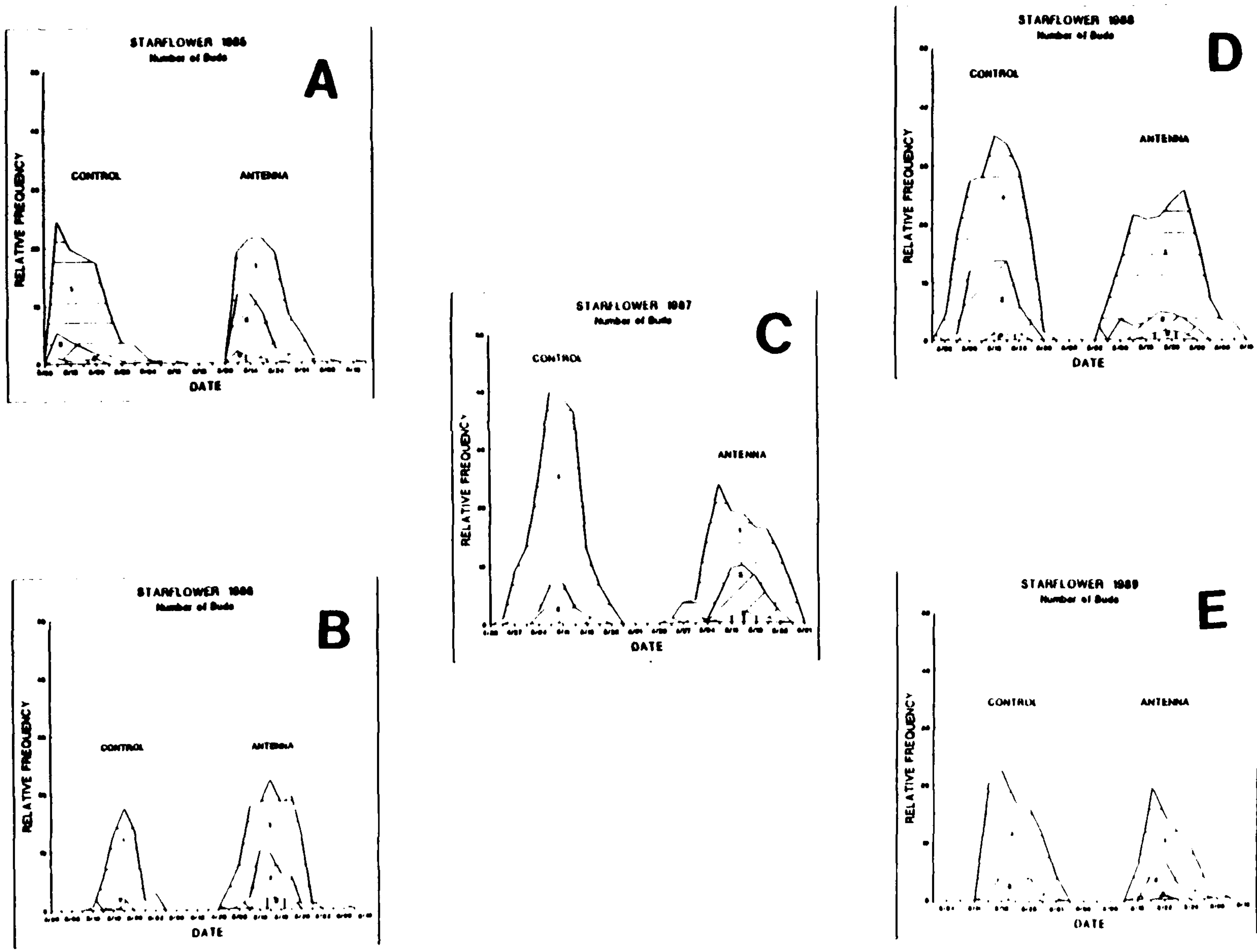


Figure 3.2: Relative frequency for number of plants with one or more flowers by sampling date on the antenna site and the control site for 1985 (A), 1986 (B), 1987 (C), 1988 (D), and 1989 (E).

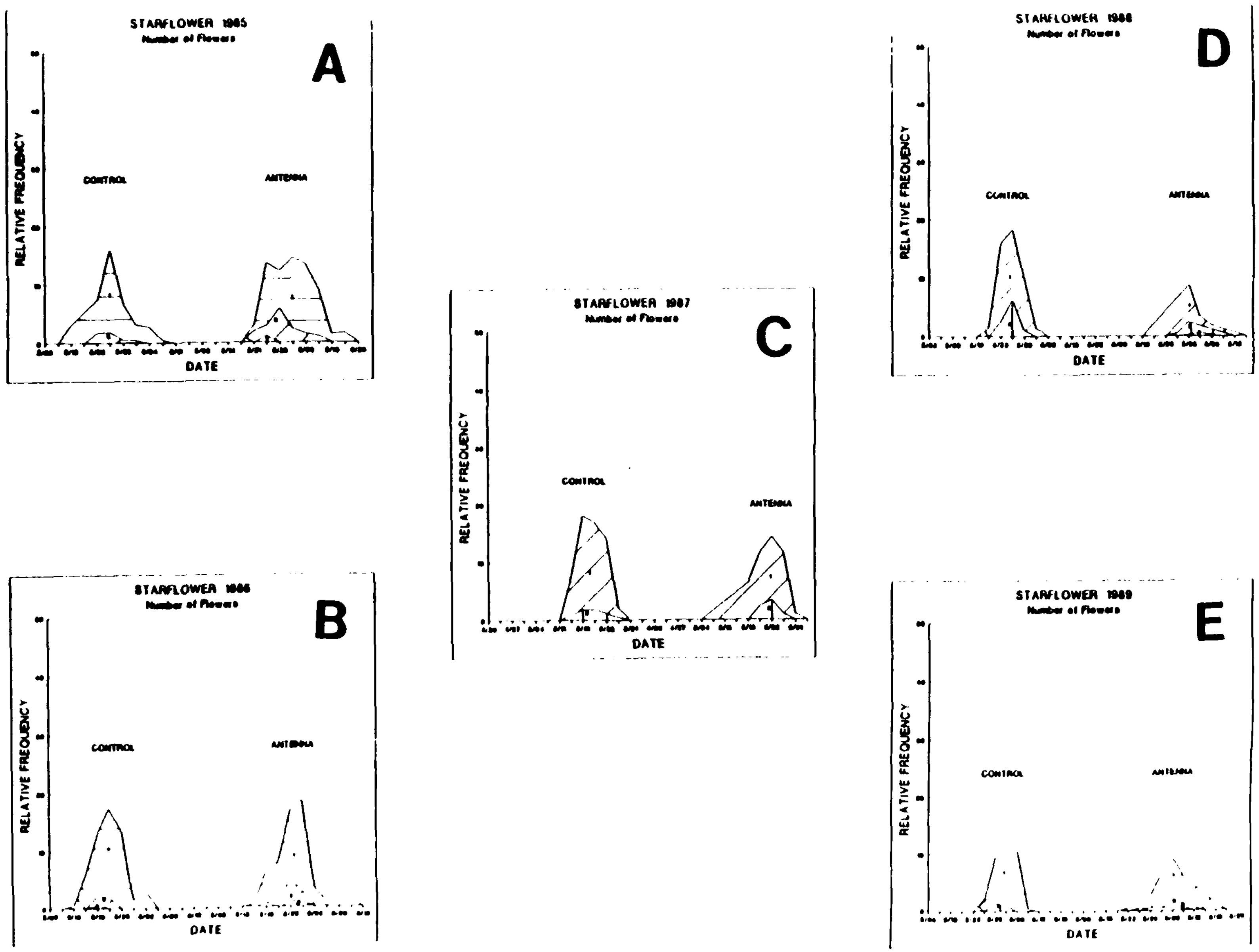
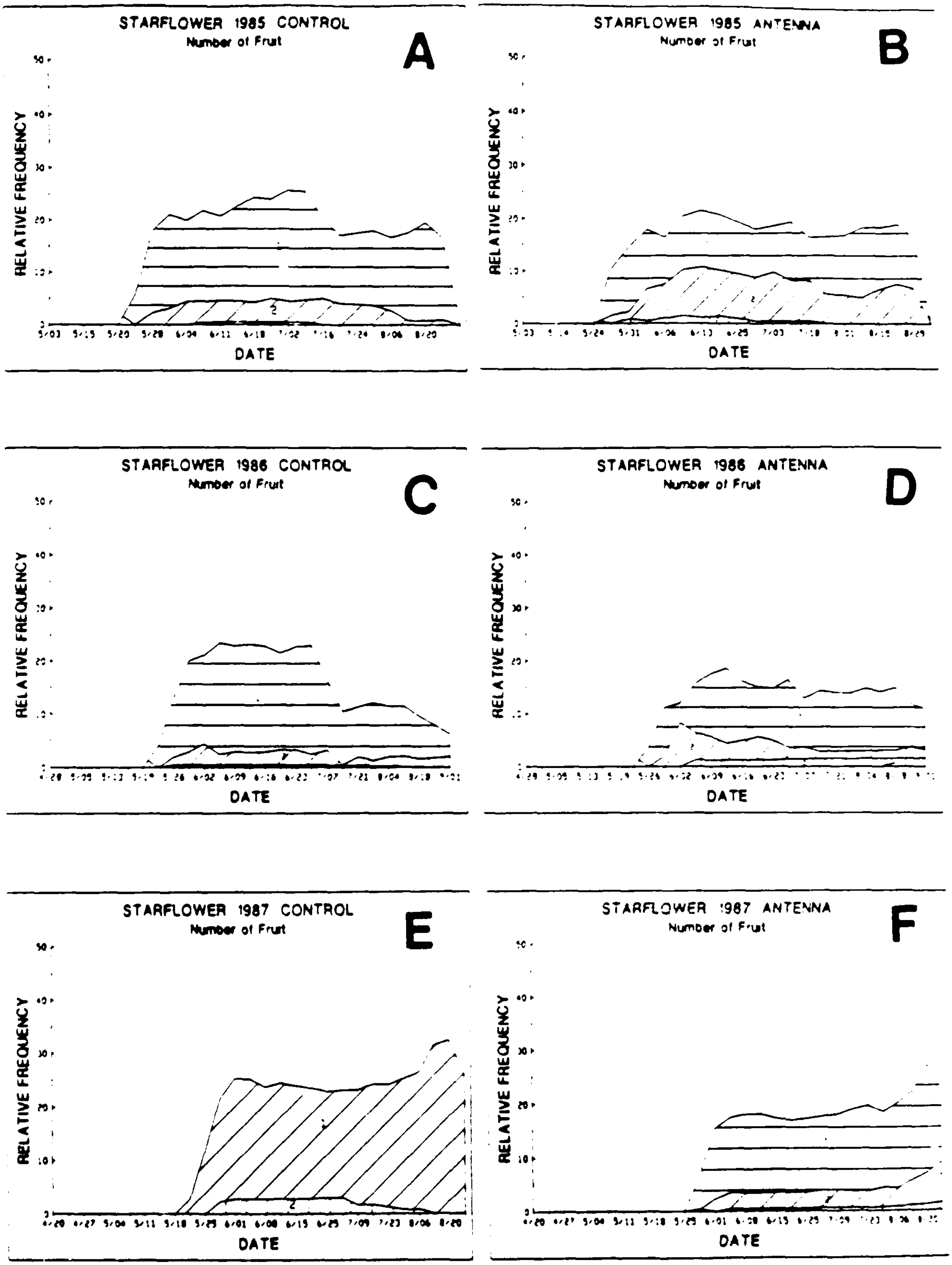


Figure 3.3: Relative frequency for number of plants with one or more fruit by sampling date on the control site 1985 (A), 1986 (C), 1987 (E), 1988 (G), and 1989 (H) and the antenna site in 1985 (B), 1986 (D), 1987 (F), 1988 (H), and 1989 (I).



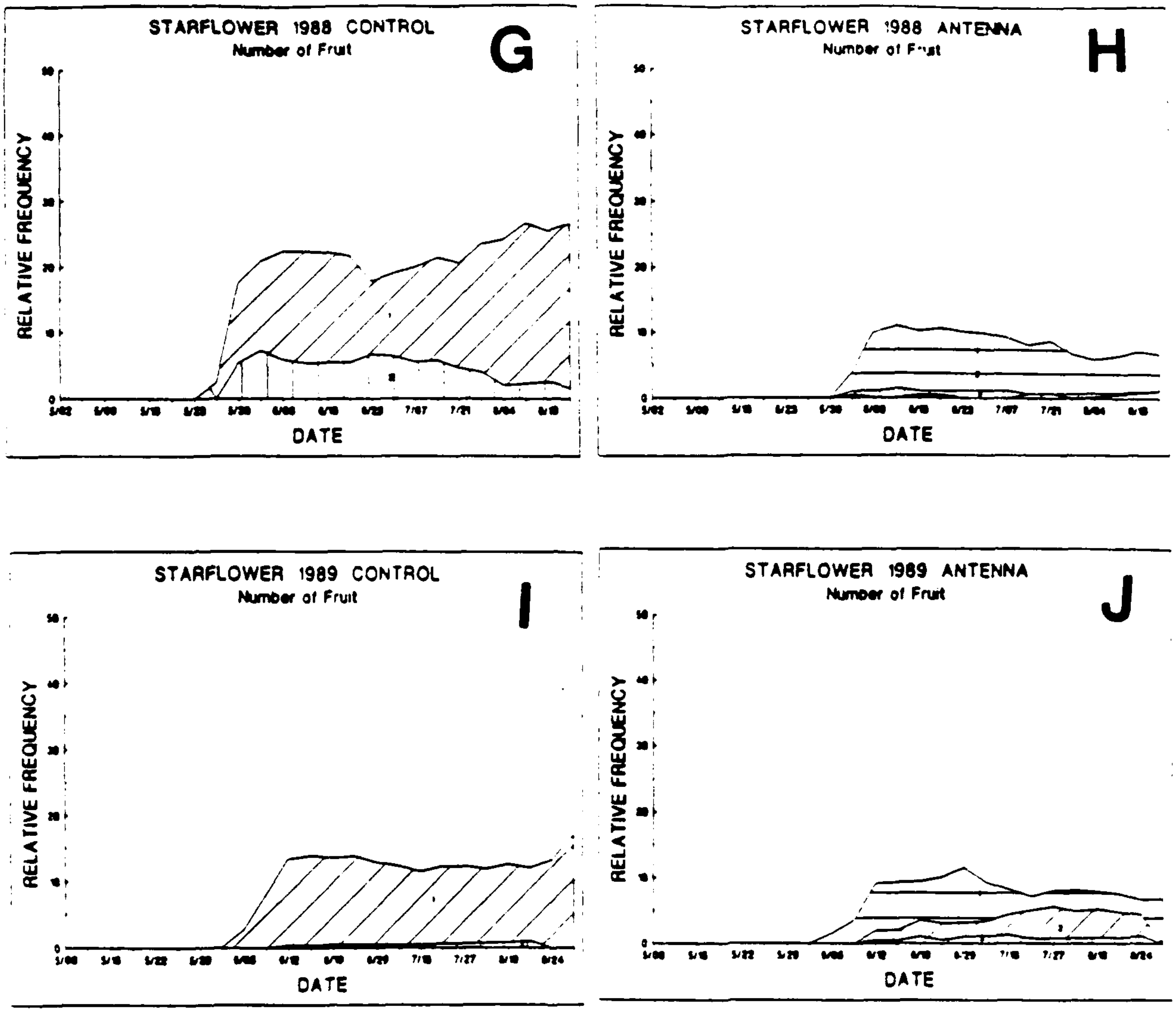
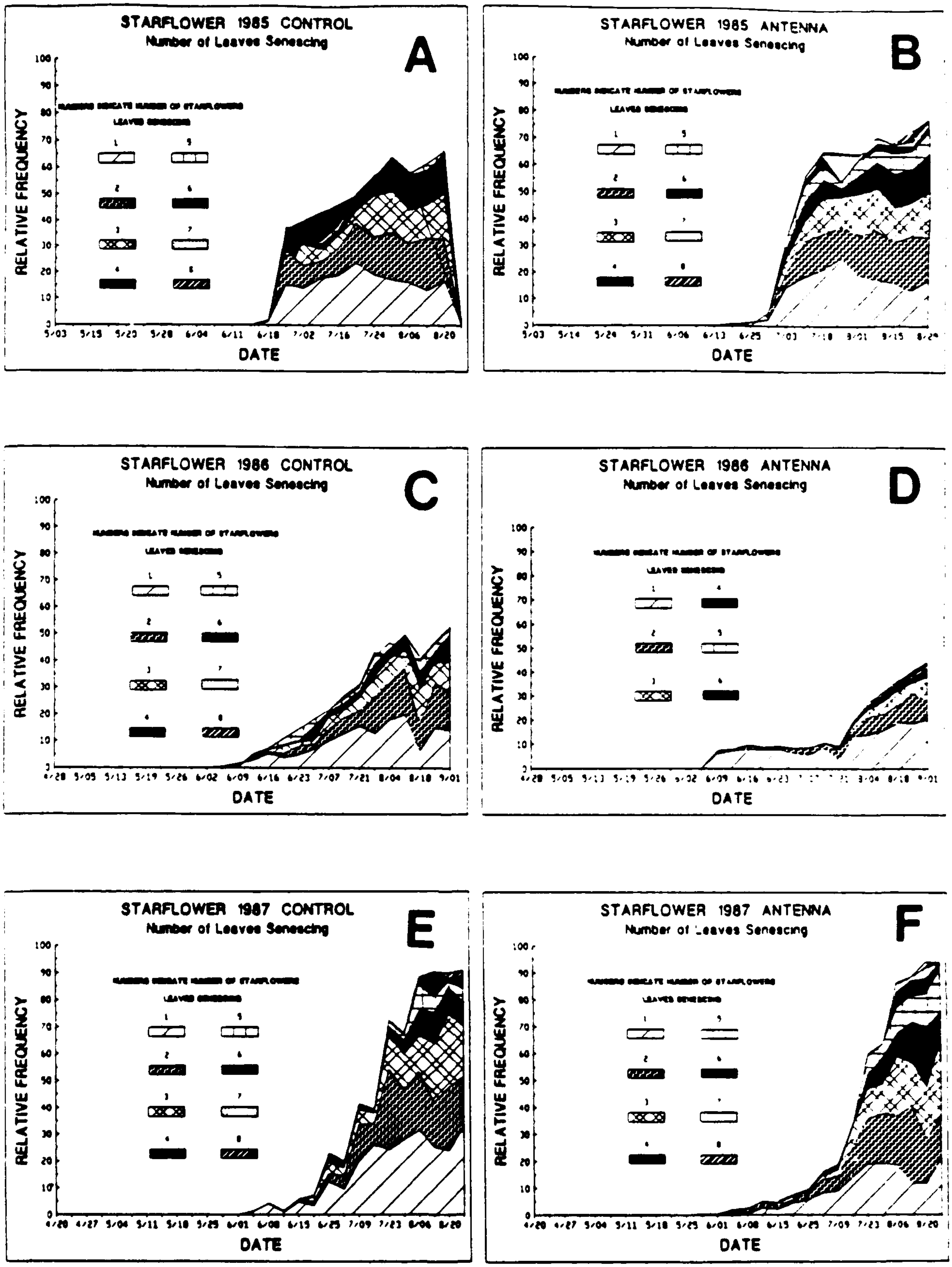
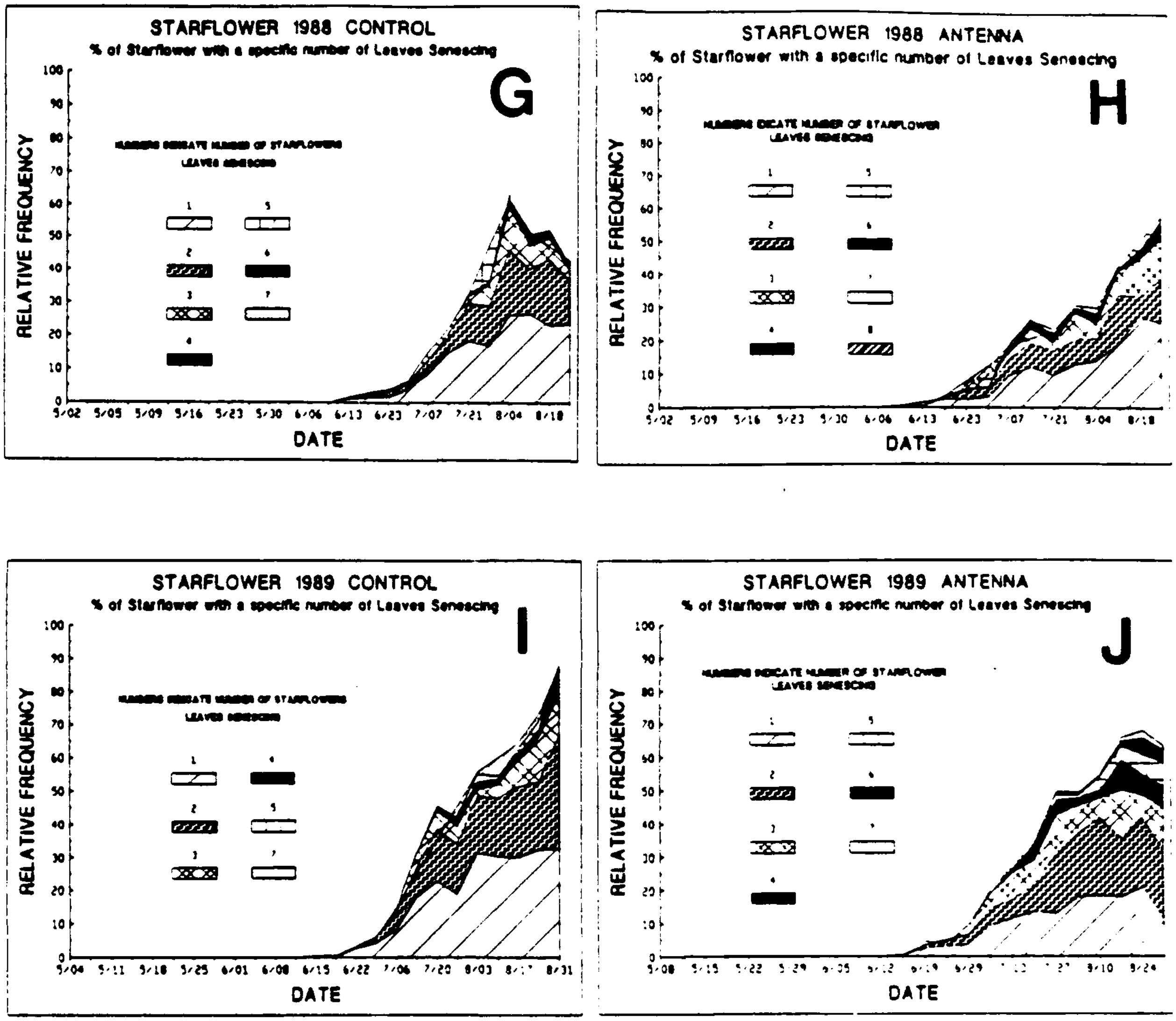

STARFLOWER 1988 CONTROL
Number of Fruit
G
RELATIVE FREQUENCY
DATE
STARFLOWER 1988 ANTENNA
H
RELATIVE FREQUENCY
DATE
STARFLOWER 1989 CONTROL
Number of Fruit
I
RELATIVE FREQUENCY
DATE
STARFLOWER 1989 ANTENNA
Number of Fruit
J
RELATIVE FREQUENCY
DATE

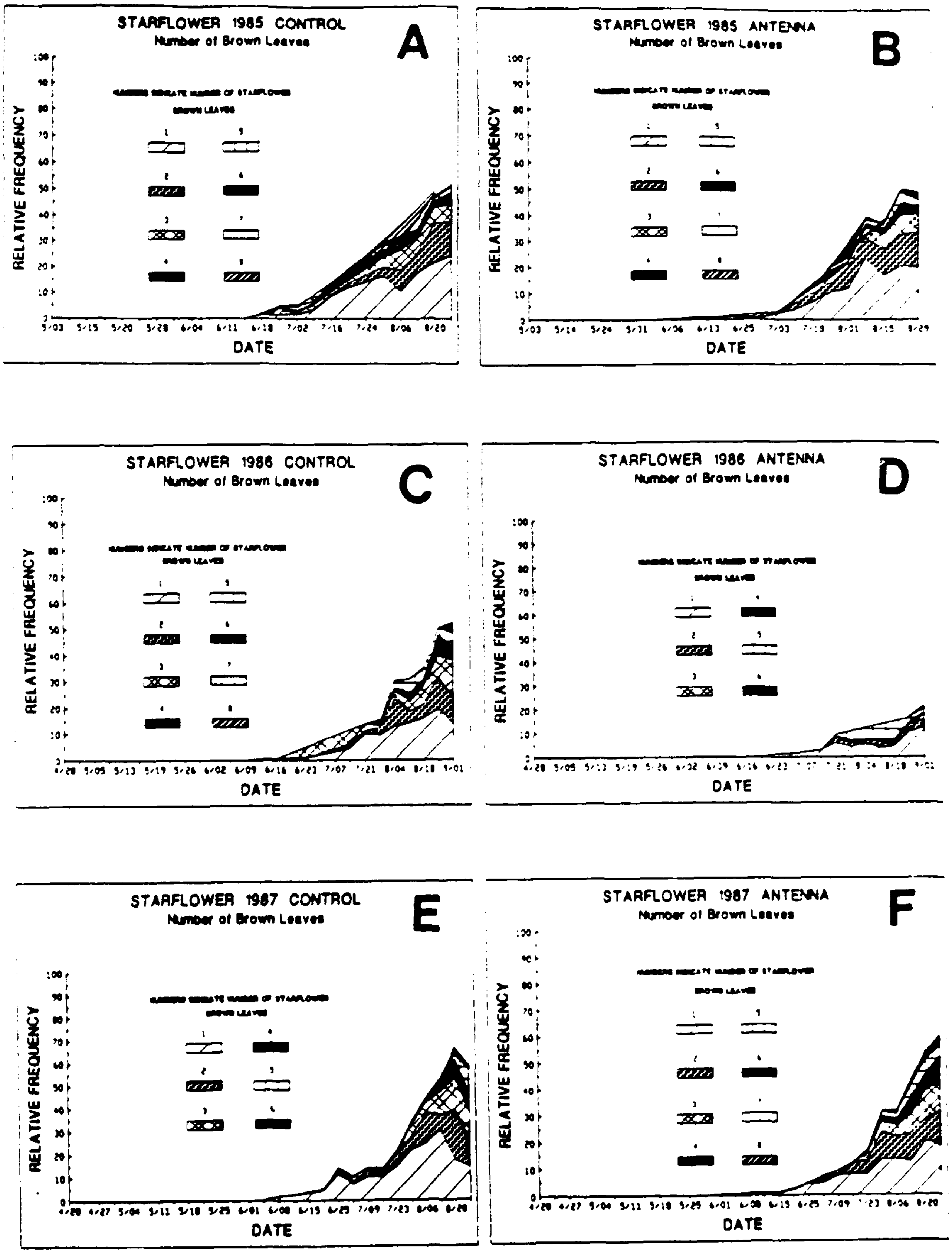
Figure 3.4: Relative frequency for number of plants with one or more leaves senescing by sampling date on the control site 1985 (A), 1986 (C), 1987 (E), 1988 (G), and 1989 (H) and the antenna site in 1985 (B), 1986 (D), 1987 (F), 1988 (H), and 1989 (I).





STARFLOWER 1988 CONTROL
% of Starflower with a specific number of Leaves Senescing
G
RELATIVE FREQUENCY
DATE
STARFLOWER 1988 ANTENNA
% of Starflower with a specific number of Leaves Senescing
H
RELATIVE FREQUENCY
DATE
STARFLOWER 1989 CONTROL
% of Starflower with a specific number of Leaves Senescing
I
RELATIVE FREQUENCY
DATE
STARFLOWER 1989 ANTENNA
% of Starflower with a specific number of Leaves Senescing
J
RELATIVE FREQUENCY
DATE

Figure 3.5: Relative frequency for number of plants with one or more brown leaves by sampling date on the control site 1985 (A), 1986 (C), 1987 (E), 1988 (G), and 1989 (H) and the antenna site in 1985 (B), 1986 (D), 1987 (F), 1988 (H), and 1989 (I).



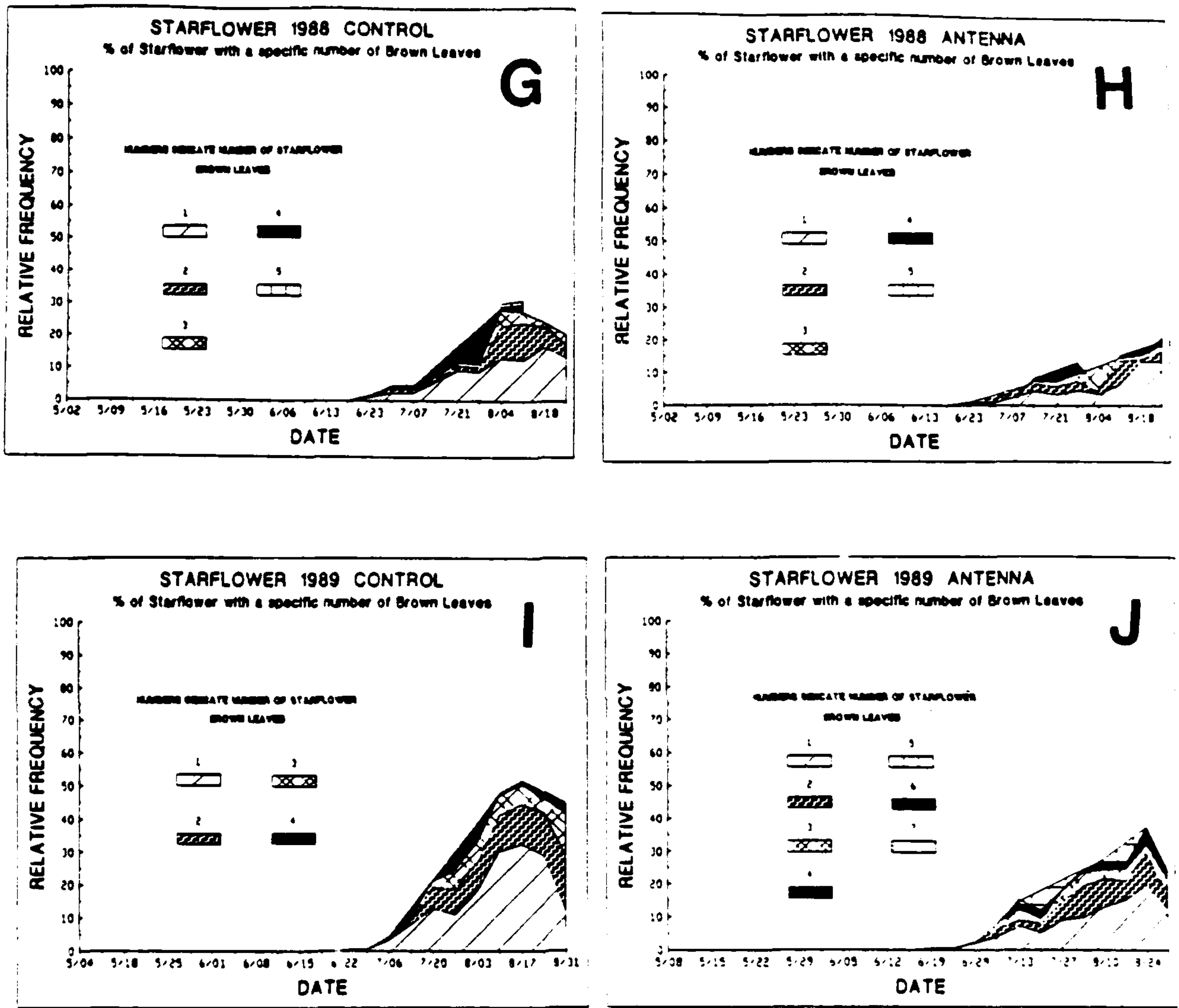
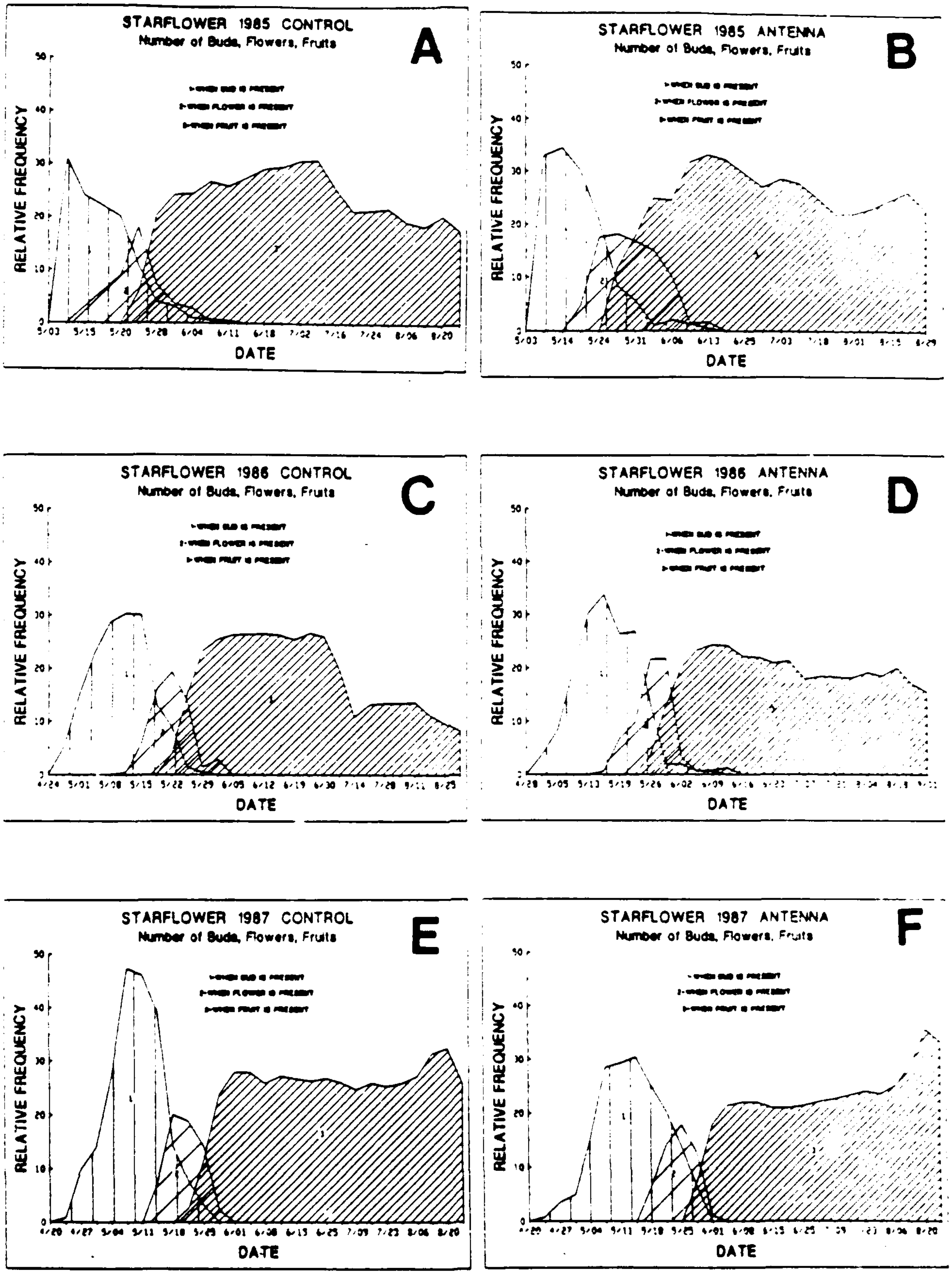
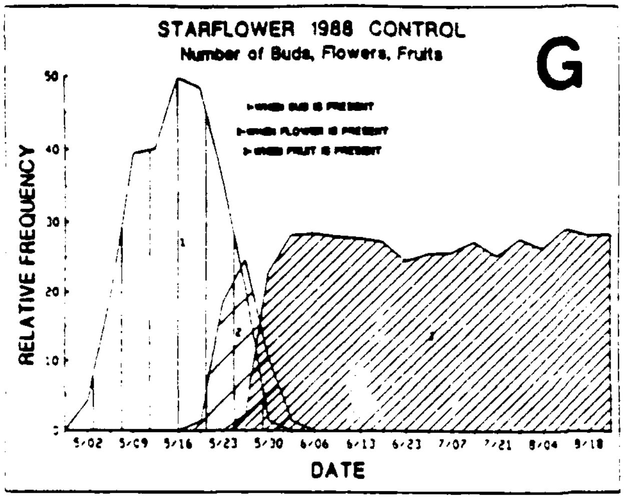
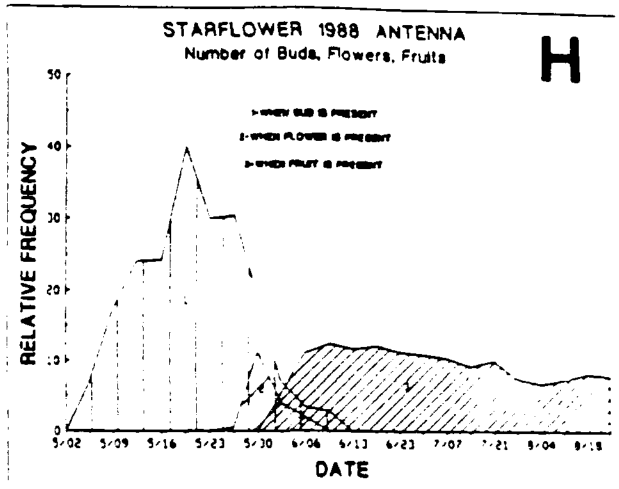

STARFLOWER 1988 CONTROL
% of Starflower with a specific number of Brown Leaves
G
RELATIVE FREQUENCY
DATE
STARFLOWER 1988 ANTENNA
% of Starflower with a specific number of Brown Leaves
H
RELATIVE FREQUENCY
DATE
STARFLOWER 1989 CONTROL
% of Starflower with a specific number of Brown Leaves
I
RELATIVE FREQUENCY
DATE
STARFLOWER 1989 ANTENNA
% of Starflower with a specific number of Brown Leaves
J
RELATIVE FREQUENCY
DATE

Figure 3.6: Comparison of the relative frequency and proportion of plants with one or more buds, flowers, and fruit by sampling date on the control site 1985 (A), 1986 (C), 1987 (E), 1988 (G), and 1989 (H) and the antenna site in 1985 (B), 1986 (D), 1987 (F), 1988 (H), and 1989 (I).

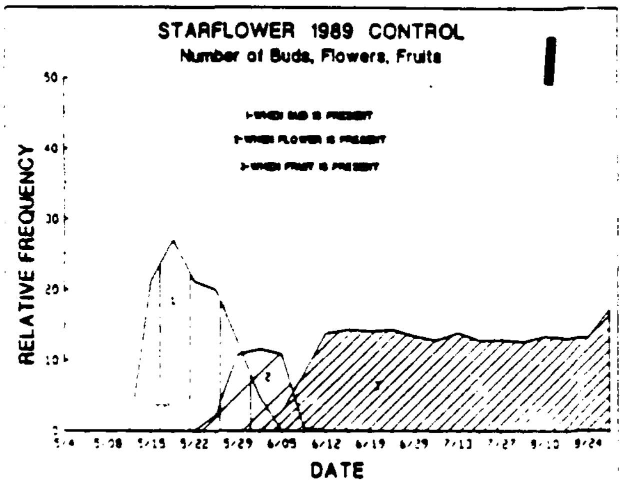




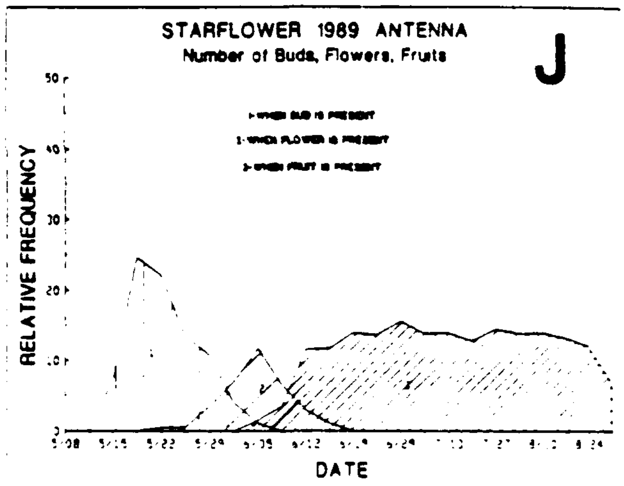
STARFLOWER 1988 CONTROL
Number of Buds, Flowers, Fruits
G
RELATIVE FREQUENCY
DATE



STARFLOWER 1988 ANTENNA
Number of Buds, Flowers, Fruits
H
RELATIVE FREQUENCY
DATE



STARFLOWER 1989 CONTROL
Number of Buds, Flowers, Fruits
I
RELATIVE FREQUENCY
DATE



STARFLOWER 1989 ANTENNA
Number of Buds, Flowers, Fruits
J
RELATIVE FREQUENCY
DATE

Table 3.1. Means, standard deviations, and significant relationships by site and location for starflower stem length, leaf length, and leaf width (Different letters indicate significant differences in the means ($p < 0.05$)).

Site and Location	STEM LENGTH Mean	Standard Deviation
Control - Unhandled	6.76a	3.99
Control - Handled	6.16a	3.04
Antenna - Unhandled	5.39b	2.96
Antenna - Handled	6.04b	2.76

Site and Location	LEAF LENGTH Mean	Standard Deviation
Control - Unhandled	3.45b	1.85
Control - Handled	3.34b	1.39
Antenna - Unhandled	3.59a	1.78
Antenna - Handled	3.90a	1.60

Site and Location	LEAF WIDTH Mean	Standard Deviation
Control - Unhandled	1.27a	0.61
Control - Handled	1.24a	0.47
Antenna - Unhandled	1.41b	0.61
Antenna - Handled	1.46b	0.50

control sites cannot be discerned except in the proportion of plants flowering.

Analysis of covariance (ANCOVA) was used to determine if climatic and microsite characteristics could be used to explain differences in stem expansion (cm/time period), leaf expansion (cm/time period), and leaf area expansion (cm^2/time period) between sites (antenna vs control), years, and site by years (Table 3.2). The same ANCOVA was used in 1989 as in 1988 and 1987. Error terms (1 and 2) for this year included sampling period (P) as in 1987. Because of the evident subplot variation along the sampling transect, additional information on the basal area and canopy coverage associated with each subplot was taken in 1989. Basal area by major tree species and total basal area were measured for each subplot using a 10 factor prism. Canopy coverage on the ground and at 4.5 feet were measured using a densiometer.

Table 3.2. Analysis of Covariance table for stem expansion, leaf expansion, and leaf area expansion.

Source of Variation	df	SS	MS	F
Year	4	SS_y	MS_y	MS_y/MS_{e1}
Covariates	#	SS_{cy}	MS_c	MS_c/MS_{e1}
Error 1 (P/Y)	40-#	SS_{e1}	MS_{e1}	
Site	1	SS_s	MS_s	MS_s/MS_{e2}
Site by Year	4	SS_{sy}	MS_{sy}	MS_{sy}/MS_{e2}
Covariates	#	SS_{cs}	MS_{cs}	MS_{cs}/Ms_{e2}
Error 3 (SxP/Y)	40-#	SS_{e2}	MS_{e2}	

In the initial analysis of variance without covariates, stem expansion, leaf expansion, and area expansion on the antenna site were significantly different from the control site (Table 3.3A) Year and site/year interactions were also determined to be significantly different (Table 3.3A). Prior to ANCOVA, scatterplots of soil temperature degree days running total versus the response variables indicated that the variation in the response variables increased with increasing soil temperature (e.g.non-constant variance). This problem was solved by taking the natural log of soil temperature degree days running total. Correlations were then calculated between starflower measurments and climatic and microsite variables. The variables were most highly correlated to leaf area expansion and leaf length expansion were 1) maximum solar radiation (SOLMX) (r=-0.42, -0.43, respectively), 2) natural log of soil temperature degree days running total at 10 cm (LST10DRT) (r=0.58, 0.63, respectively), 3) bigtooth aspen

Table 3.3. Results of ANCOVA (p values) to determine significant differences in stem expansion (STEM), leaf expansion (LGTH), and leaf area expansion (LAREA) between sites, years, and years by site.

A) No Covariates

Source of Variation	STEM	LGTH	LAREA
Year	0.00	0.00	0.00
Site	0.00	0.00	0.00
Site by Year	0.00	0.00	0.00

B) Covariates for Leaf Length (LGTH) and Leaf Area (LAREA). Bigtooth Aspen Basal Area (BTABA) + Northern Red Oak Basal Area (NROBA) + Natural Log (Soil Temperature Degree Days Running Total at 10 cm)/BTABA + Natural Log (Soil Temperature Degree days Running Total at 10 cm)/NROBA + Maximum Solar Radiation/BTABA + Maximum Solar Radiation/NROBA.

Source of Variation	LGTH	LAREA
Year	0.01	0.14
Site	0.88	0.96
Site by Year	0.34	0.72

C) Covariates for Stem Length (STEM). - Bigtooth Aspen Basal Area (BTABA) + Northern Red Oak Basal Area (NROBA) + Maximum Solar Radiation/BTABA + Maximum Solar Radiation/NROBA.

Source of Variation	STEM
Year	0.00
Site	0.47
Site by Year	0.91

basal area (BTABA) (r=0.34, 0.33, respectively), and 4) northern red oak basal area (NROBA) (r=-0.33, -0.32, respectively). Interactions between the climate variables and microsite variables were also highly correlated to leaf area expansion and leaf length expansion (ie., LST10DRT/BTABA (r= -0.26, 0.23, respectively), and LST10DRT/NROBA (r=0.30, 0.32, respectively) SOLMX/BTABA (r= -0.30, -0.31, respectively)). Although not highly correlated to leaf area and leaf length expansion, the interaction SOLMX/NROBA (r= -0.01, 0.05,

respectively) was used as a covariate to explain the high component of northern red oak trees on the control site. Due to multicollinearity among these variables only BTABA, NROBA, and their corresponding interactions were used in the analysis. The use of these covariates explained significant amounts of variation in leaf area expansion and leaf length expansion between sites and among site by years but not among years (Table 3.3B). The same covariates used for leaf length and area expansion could not be used for stem expansion. The reason for this is unknown, however, stem expansion may be related to the amount of carbon stored in the roots from the previous year and to initial seasonal conditions. The variables most highly correlated to stem expansion were 1) maximum solar radiation (SOLMX) ($r=0.14$), 2) natural log of soil temperature degree days running total at 10 cm (LST10DRT) ($r=0.21$), 3) bigtooth aspen basal area (BTABA) ($r=0.27$), and northern red oak basal area (NROBA) ($r= -0.23$). Interactions between the climate variables and microsite variables were highly correlated to stem expansion SOLMX/BTABA ($r=-0.16$) and SOLMX/NROBA ($r=0.02$). Due to multicollinearity among covariates only BTABA, NROBA, and the corresponding interactions with solar radiation were used in the analysis. These covariates explained significant amounts of variation in stem expansion between sites and among site/year interactions (Table 3.3C). Yearly differences could not be explained. The addition of other climatic and microsite factors as covariates did not yield better results. The transverse east west ELF field was the most highly correlated with leaf area ($r=0.29$), leaf length ($r=0.30$), and stem length expansion ($r=0.26$). This field and others were also highly related to some of the measured climatic and microsite factors and may be confounded with soil and vegetation on the herbaceous reserve. Monitoring the effects of ELF fields on stem, leaf, and area expansion will continue.

Morphological Characteristics

A separate greenhouse study was begun in 1989 to evaluate the effects of constant light and temperature regimes on starflower populations from the antenna site and the control site. Observations in the past years suggested a clonal difference between these two populations. Starflower plants and soils from each site were collected off the herbaceous transects and put in containers. These plants were grown in the same light and temperature regime, then measured in early September to determine if there were morphological differences between the two sites. This study indicated that there are significant differences ($p < 0.05$) in the mean number of leaves on starflower plants on the antenna (7.0) versus the control site (6.0). Leaf width was significantly ($p < 0.05$) greater on the antenna (1.58 cm) versus the control (1.15). Other morphological characteristics were not significantly different. These results are consistent with means estimated

from the field study. Work will continue to evaluate the effects of ELF on these plants.

Four buds per plant were observed on the antenna site this year (Figure 3.1E). The amount of plants that produced flowers were lower on the antenna site versus the control site (Figure 3.2E). The number of flowers per plant were greater on the antenna site. More fruit (>2 fruits per plant) were observed on plants on the antenna site versus those on the control site (Figures 3.3I and 3.3J). However, as with the number of buds, and the number of flowers, more plants produced fruit on the control site than on the antenna site. The antenna and control sites exhibited the same percent plants that produced yellow (Figures 3.4I and 3.4J). The percent of plants with brown leaves were lower in number on the antenna than on the control site (Figures 3.5I and 3.5J). Except for the proportion of plants flowering, similar relationships were seen in the 1985, 1986, and 1987 growing seasons. The effects of ELF fields on is not evident at this time.

Using regression analysis, linear equations were fit to observations of leaf area using leaf length and leaf width measured on destructively sampled starflower plants off the herbaceous reserves for each year (1986, 1987, 1988, and 1989) on each site (Table 3.5). The independent variable of leaf

Table 3.5. Leaf area (LA) equations for each site in each year and for all sites and all years using leaf width (Lw) and leaf length (Ll).

Site (Year)	Equation	$S_{y.x}$[1]
Control Site (1986)	LA = 0.09 + 0.55 (Lw x Ll)	0.20
Control Site (1987)	LA = 0.11 + 0.56 (Lw x Ll)	0.18
Control Site (1988)	LA = 0.40 + 0.52 (Lw x Ll)	0.68
Control Site (1989)	LA = 0.05 +.0.57 (Lw x Ll)	0.18
Antenna Site (1986)	LA = 0.13 + 0.55 (Lw x Ll)	0.26
Antenna Site (1987)	LA = 0.13 + 0.56 (Lw x Ll)	0.34
Antenna Site (1988)	LA = 0.32 + 0.52 (Lw x Ll)	0.60
Antenna Site (1989)	LA = 0.05 + 0.56 (Lw x Ll)	0.24

[1] Standard error of regression

width x leaf length explained 99 percent of the variation in leaf area for both sites in 1986, 1987, and 1989. Ninety-two and 96 percent of the variation in leaf areas was explained using the variable leaf width x leaf length for the control and the antenna, respectively, in 1988. Higher standard errors occurred with the development of the 1988 curves (Table 3.5). In 1989, the standard error of the regression was similar to 1986 and 1987. Possible causes of increased error in 1988 were attributed to inaccuracies in leaf length and leaf width measurements and/or leaf sampling in the field. These problems seem to be corrected for the 1989 data.

Regression coefficients (intercepts and slopes) were tested to determine if there were significant differences ($p < 0.05$) between sites (antenna vs control) and among years. Site-year interactions were also examined. Significant yearly differences ($p < 0.001$) in both the slopes and the intercepts were determined. Intercepts for the antenna and control sites in 1988 were again significantly greater than for 1986, 1987, and 1989 and the intercept for 1989 was significantly lower than all other years. Slopes for the antenna and control sites were significantly lower in 1988 than for 1986, 1987, 1989. These differences may be due to the increase in the amount of solar radiation in 1988 compared to other years (Element 1, this report). There were no differences in coefficients between sites or among site/year interactions. Leaf areas will continue to be measured and prediction equations developed using leaf length and leaf width.

Summary

At this time, significant variation in stem expansion, leaf expansion, and leaf area expansion between the antenna and the control site can be explained using microsite basal areas, soil temperature degree days running total at 10, maximum solar radiation, and interactions between these variables. The ELF fields in 1988 and 1989 have no apparent affect on starflower's leaf and stem expansion. The ELF field are, however, highly related to microsite and climatic variables. Monitoring starflower's morphological and phenological characteristics between sites will continue. Monitoring the effect of handling on plant size will also continue.

Element 4. MYCORRHIZAE CHARACTERIZATION AND ROOT GROWTH

Mycorrhizae of plantation red pine seedlings have been chosen as sensitive biological indicators to reflect perturbations which might be caused by ELF fields. Mycorrhizae are symbiotic structures representing a finely balanced physiological relationship between tree roots and specialized fungi, providing mutual benefit to both partners of the symbiosis. Mycorrhizal fungi are obligately bound to their host requiring photosynthate from the tree for their energy source. In return, the matrix of mycorrhizal fungus mycelium which permeates the forest floor and mineral soil from colonized roots provides the host tree with scarce minerals and water more efficiently than possible without its fungal partner. Although many types of mycorrhizae occur on these sites, this study will examine only ectomycorrhizae fungi formed on red pine root systems.

Mycorrhizae, being composed of two kinds of organisms (though sometimes several fungi may be involved) that make up a major part of the forest ecosystem, are likely to be sensitive indicators of subtle environmental perturbations. Mycorrhizal fungi are obligate symbionts, directly dependent on their partner's physiology for their health. Thus mycorrhiza formation and numbers will be sensitive to factors affecting either the fungus component or the host plant component.

Mycorrhizae have been selected for evaluation in other studies which require sensitive indicators of subtle environmental changes. Recent studies designed to monitor the effects of acid rain on the forest ecosystem used mycorrhizal numbers as the parameter of assessment (Reich *et al.* 1985, Shafer *et al.* 1985, Stroo and Alexander 1985, Dighton and Skeffington 1987). Similar studies examined mycorrhizae as affected by ozone and air pollution (Kowalski 1987, Reich *et al.* 1985, Mejstrik and Cudlin 1987) and heavy metal buildup in soils (Jones and Hutchinson 1986). The effects of ELF fields not directly evoking a measurable tree response could detectably alter the more discriminating mycorrhizal fungus component. Data regarding mycorrhizae of a host tree may also be used to substantiate responses seen in other measures of tree productivity.

Populations of mycorrhizae on each red pine plantation site are compared with each other at monthly intervals during the growing season and with corresponding monthly intervals during the growing season from previous years. The basic experimental units are individual red pine seedlings. Mycorrhizae are categorized into morphological types which are produced by different fungal associations with red pine seedlings. Changes in both the frequency of occurrence for different mycorrhizal types and the total numbers of mycorrhizae per seedling are quantified for analysis both within and among years as well as among sites. Data for analysis are expressed as the total number of mycorrhizae per

gram of seedling root mass (oven dry weight (o.d.w.) 60°C). The working null hypothesis states that there are no differences in population densities of different types of mycorrhizal root tips on red pine seedlings at the Ground Antenna and Control sites, before or after the ELF antenna becomes operational. Other changes that could occur are reflected by possible alternative hypotheses such as; 1) shifts in population species composition and 2) changes in the character of mycorrhizal morphology type.

Sampling and Data Collection

In conjunction with Element 2, Tree Productivity, fifteen red pine seedlings per site (five per subplot replicate) were sampled for six months during the 1989 growing season, as was done the previous three years. Seedlings for mycorrhizal analysis were simultaneously measured for aboveground growth parameters and moisture stress. To retrieve mycorrhizae-bearing lateral roots, the seedling's root system was excavated using a shovel and produced a soil sample approximately 22 cm in diameter and 22 cm deep. Red pine seedling lateral roots were extracted from this sample in the field to obtain approximately 30 to 60 cm of total root length. Lateral roots from each seedling with adherent soil were wrapped tightly in individual plastic bags, placed in a cooler and transported to the laboratory where they were refrigerated. Within two to three days the lateral roots were rinsed first in a small volume of distilled water (1:1 water to root/soil volume) for rhizosphere soil pH determination, then washed gently in tap water, placed in a fresh volume of tap water and refrigerated. Approximately 0.25 g roots (fresh weight) per sample were removed at this time for actinomycete enumeration (ELF, Litter Decomposition and Microflora Study). Counting mycorrhizal tips began immediately and was usually completed within three weeks of the field sampling date.

A shallow white pan containing a small amount of water was used during the root sectioning and counting operation. The roots were cut to obtain as many 3 cm segments and as few segments less than 3 cm as possible. Branching portions were separated from segments if they were greater than 1 cm in length. Branching portions less than 1 cm were included as part of the root segment to which they were attached. As each 3 cm root segment was counted, its diameter and number of mycorrhizae were recorded. A mycorrhiza is defined, for counting purposes in this study, as a terminal mycorrhizal root tip at least 1.0 mm in length; hence a mature dichotomously branched mycorrhizal root tip would be tallied as two mycorrhizae. Upon completion of counting a total of 30 3 cm root segments per seedling, counted root segments were collectively dried at 60°C to constant mass and weighed. Mycorrhiza counts for each seedling are expressed as mycorrhizae per gram (o.d.w.) of lateral root. This measure

has been used in other root studies examining mycorrhizae dynamics in forest ecosystems (Harvey *et al.* 1987).

The most common mycorrhizae present continue to be represented by a fairly uniform morphology. They range in color from a tan to a deep red-brown color and are formed primarily by *Thelephora terrestris* and/or *Laccaria laccata* (*sensu lato*, Fries and Mueller 1984). These mycorrhizae were designated as Type 3 mycorrhizae. Many of the mycorrhizae have acquired a nearly black to deep jet-black color due to colonization by *Cenococcum graniforme*, an abundant mycorrhizal fungus in the original and surrounding hardwood forests, which were designated as Type 5 mycorrhizae. White to tan floccose forms are occasionally found, presumably colonized by *Boletus, Hebeloma, Paxillus* or *Suillus* spp., which have been designated as Type 6 mycorrhizae. Though variations occur within mycorrhizal morphology types, all fit within the grouping of these three main types. A dissecting microscope was used, but was not always necessary, to distinguish the mycorrhizal types. Morphology types are tallied separately and then totaled for each seedling. Non-mycorrhizal root tips are easily distinguishable as white root tips composed entirely of plant tissue, obviously lacking a fungal component.

Descriptions of Red Pine Mycorrhizal Morphology Types

Type 3 Mycorrhiza

Macroscopic: Light buff to dark red brown, sometimes nearly black, usually lighter at the apex; 2-10 mm long x 0.25-1.0 mm diameter; mono- or bipodal, occasionally multiply bifurcated and in mass forming coralloid clusters; plump and straight when short, but spindly and often crooked when long, usually somewhat constricted at the base.

Microscopic: Surface hyphae sparse, 2-3 um diameter, bearing clamps, setae scattered, often clustered in bunches of 4-8, mostly 50-80 um long; mantle 10-20 um thick, thinner over apex, hyphae forming conspicuous interlocking, "jig-saw puzzle-like" pattern; cortical cells red-brown except over apex where they are colorless; Hartig net hyphae bulbous and also forming interlocking pattern.

Comments: This is the common and most numerous type of mycorrhiza found originally on the nursery red pine seedlings and which is still predominant. The causal fungi, as evidenced by cultural isolation, are most often *Laccaria laccata (sensu lato)* and *Thelephora terrestris*, though other fungi may also produce similar mycorrhizae. It is worth noting that *L. laccata (sensu lato)* abounds in the surrounding forests and fruits abundantly on the plantation sites. This fungus might therefore be expected to maintain its dominance in the plantation seedlings. *Thelephora terrestris* has also been observed fruiting on the plantation sites.

Type 5 Mycorrhiza

Macroscopic: Black, sometimes with lighter apex; usually fuzzy with abundant attached, coarse hyphae; 1-3 mm long x 0.5-10 mm diameter; mono or bipodal, seldom multiply bifurcated; often appearing as if dark hyphae are enveloping Type 3 mycorrhizae.

Microscopic: Surface hyphae dark-brown to black, 3-6 um diameter, septate; setae arising from central stellate points of interlocking surface hyphae, setae 100 um or greater in length; mantle 10-30 um thick, mantle surface of coiled and interlocking hyphae; cortical cells dark and covered directly with hyphae of the same type observed with Type 3 mycorrhizae; Hartig net hyphae bulbous and also with interlocking pattern.

Comments: This is a later successional stage mycorrhiza, appearing as a dark sheath over an earlier developed mycorrhiza. The causal fungus is *Cenococcum graniforme*, which is commonly isolated from these mycorrhizae. Hypogeous fruit bodies of *Elaphomyces* sp., the anamorph of *C. graniforme*, have been collected in the surrounding forest, indicating that adequate inoculum is available.

Type 6 Mycorrhiza

Macroscopic: White to light gray-brown, mottled and silvery; 2-5 mm long x 0.5-1.0 mm diameter; abundant loosely-bound surface hyphae often binding soil matter; mono- or bipodal often in large coralloid clusters of multiply bifurcated tips; in water, air bubbles become entrapped in loose surface hyphae causing freed individual mycorrhizae to float.

Microscopic: Surface hyphae colorless, abundant, septate or not, 3-6 um diameter, multiply branched at septae; setae lacking; mantle of loose hyphae 24-100 um thick, cortical cells red-brown covered with interlocking hyphae similar to Type 3; Hartig net hyphae bulbous and also with interlocking pattern.

Comments: This also appears to be a later successional stage mycorrhiza type forming a sheath over an earlier developed mycorrhiza. Presumably the responsible fungi colonize new root tips as well. Based on cultural characteristics of isolated fungi, the causal fungi probably belong to the families Boletaceae, Cortinariaceae or Paxillaceae. Fruiting bodies of these families were common in the original forest and fruit abundantly in the surrounding forest, providing adequate and readily available inoculum.

Though red pine seedlings were outplanted on the study sites in June 1984, data from that year are not being compared with subsequent years for two reasons. First, 1984 was the year of plantation establishment; nursery seedlings are small and planting shock is known to have a significant effect on seedling root systems. Second, there are no ambient weather

or soil data available for 1984 to use in the covariate analysis. For years following 1984 site comparisons within and between years consider the parameters of non-mycorrhizal root tips per gram, Type 3 mycorrhizae per gram, Type 5 mycorrhizae per gram, Type 6 mycorrhizae per gram, and total mycorrhizae per gram of seedling root mass (o.d.w.). A significance level of p=0.05 with Duncan's Multiple Range Test was used to detect differences between means being tested. Comparisons among sites, years, and site by year will be the primary focus of the statistical analysis. To facilitate this, data on mycorrhizae per gram of seedling root mass were analyzed using analysis of covariance, with weather and soil variables applied as covariates.

Progress

Non-mycorrhizal root tips were again not encountered in the 1989 season. Since 1985 nonmycorrhizal root tips have continued to decline, to the extent that in 1987 none were recorded for the final month at the Ground and Control sites, and for the last four months at the Antenna site. This steady decline in uncolonized root tips is likely a function of seedling maturation, and indicates that seedlings are becoming fully adapted to native soil microflora. Non-mycorrhizal root tips remain a morphological type of interest, and will be continue to be monitored in future years, in case (hypothetically) seedlings undergo a reversion in maturity due to ELF field effects.

Type 3 mycorrhizae in 1989 continued to be the major mycorrhizal type on red pine seedling root systems at all sites (Figure 4.1A and 4.1B). This year, the control site was more like the antenna site and the ground site than in 1988. The reason for this is unclear except that, over all sites, the mean air temperature was cooler in 1989 than in 1988, 1987, and 1986 and thus would offset the affect of lower soil moistures as found on the antenna and ground sites compared with the control site. During the 1989 growing season their was a distinct increase in mycorrhizal numbers in July and August (Figure 4.1A and 4.1B). This corresponded to increases in precipitation during this time period (Element 1). Even with the increases in Type 3 mycorrhizae in 1989, this year along with 1988 had significantly lower numbers of mycorrhizae per gram of root than 1987, 1986, and 1985. These differences may be a reflection of seedling age, since this mycorrhizal type is known to be especially predominant on nursery stock. Perhaps the dry, hot weather of 1988 had a greater impact on the poorer, more rocky Ground site than on the more favorable sites, and this is evidenced by the greater differences detected there between this and previous years.

Type 5 mycorrhizae increased in June, July, and September months in 1989 (Figure 4.2A). This year was comparable to 1987, although mean numbers for the year were comparable to 1986. Statistical comparisons from year to year for any site

and month demonstrate that 1989 was more like 1987 than other years, with respect to levels of Type 5 mycorrhizae. The control site had significantly higher numbers of Type 5 mycorrhizae in May, June and July months than the antenna and ground sites. These differences may be due to the higher amount of root surface area established at the end of the growing season in 1988, thus giving new roots a better advantage at the beginning of the growing season in 1989. Type 5 mycorrhizae per gram of seedling root for 1988 were lower in number than any year since 1985. As with Type 3 mycorrhizae it may be that age of seedlings and weather factors are causing this apparent reduction in these two most common mycorrhizal types for different years.

Type 6 mycorrhizae are the least common type encountered on red pine seedling root systems on all of the study sites (Figure 4.2B). They were first observed in late 1984 on very few seedlings. In 1985, Type 6 mycorrhizae were recorded only in July and August on the Control site. In 1986, no seedlings were found with Type 6 mycorrhizae. In 1987 the occurrence of Type 6 mycorrhizae was still infrequent and sporadic (Figure 4.2B), but they were found often enough on all sites (but not all months) to make comparisons between sites for the year. In 1988, numbers of Type 6 mycorrhizae were similar to the previous year, but higher numbers are being recorded, especially later in the season. In only two months of 1988 were differences between sites significant: in May the Ground and Antenna sites had lower numbers of Type 6 mycorrhizae per gram than the Control site, and in September the Ground site had lower numbers than the Antenna site while not differing from the Control site. In 1989, however, numbers of Type 6 mycorrhizae declined with only the control and ground site having similar numbers in May and the control and antenna site having similar numbers in July (Figure 4.2B). The Antenna site still tends to be intermediate with respect to numbers of Type 6 mycorrhizae, and the Ground site leans towards having the fewest both in numbers and months encountered. This pattern may reflect site/soil conditions, in a similar way as remarked above. This apparently later stage mycorrhizal type would be expected to develop sooner on the best of the sites, the Control site, where tree growth is advancing more quickly as well (see Element 2).

At this time, there doesn't appear to be any affect of ELF fields on the number of mycorrhizal root tips per gram of dry root. In 1989, site differences were the least distinct of all years. If there are changes in mycorrhizal numbers due to ELF fields this should become evident within the next few years with the ELF antenna becoming fully operational in September, 1989.

Covariate Analysis

Covariate analysis was used to explain some of the differences in plantation seedling establishment among sites and years, by taking into account the variation in ambient weather and soil conditions among sites and years. Means and sums of ambient variables represent a period 30 days prior to each mycorrhizae sampling date. The complete list of ambient variables used is shown in Table 4.1.

Correlations were performed to find which of the ambient variables were most likely to serve as covariates to explain observed variation in mycorrhizae per gram of seedling root among sites and years. Correlation coefficients (r) for mycorrhizae per gram of seedling root with the ambient variables are also shown in Table 4.1. This year, soil and air temperatures were more highly correlated to mycorrhizal numbers than in previous years. This may be due to the cooler weather experienced in May and June this year than in 1986, 1987, and 1988. A wider variation in weather patterns may be needed to predict major changes in mycorrhizal numbers.

Analysis of variance (ANOVA) was performed with five years of data to detect differences between the various factors, and their interactions, on total mycorrhizae per gram of seedling root. Mycorrhizal numbers were not significantly different ($p<0.05$) among sites and among site and year interactions. Significant differences among years were detected mainly because this factor is time dependent and may either be related to seasonal and/or yearly growth fluctuations or to the establishment of newly planted seedlings as discussed above.

To test whether the additicn of a covariate explained yearly differences in mycorrhizal numbers analysis of covariance (ANCOVA) was performed with the five years of collected data. Table 4.2 lists probability (p) values (significance of the F statistic) after analysis of covariance using the four significantly correlated ($p<.001$) ambient parameters individually as covariates. In all cases, although p values for site factors and site and year interactions changed, yearly differences could not be explained. Yearly differences were also not explained by using combinations of ambient variables in the analysis.

Of the five ambient parameters used as covariates the one decreasing the site differences and the site and year interaction differences the most was total precipitation (PRCTOT). This ambient parameter is most likely to be effecting seedling root growth and mycorrhizal development to the greatest degree because of the effect of drought on mycorrhizal fungi. It is believed that some fungi have the ability to enhance root processes during droughty climate. It appears, however, that on these sites mycorrhizal numbers increase with increases in precipitation. Seasonal fluctuations within each year may be more important to mycorrhizal numbers than yearly differences in mean climatic data.

Table 4.1. Pearson correlation coefficients (r) calculated for total mycorrhizae per gram of seedling root with ambient parameters for the five years 1985 through 1989.

Ambient Parameter	Correlation Coefficient
AT=mean daily air temperature	.2212**
ATMN=mean minimum daily air temperature	.2051**
ATMX=mean maximum daily air temperature	.2177**
ATDD=mean air temperature degree days	.2177**
ATDDRT=air temperature degree days running total	-.2151**
ST5=mean soil temperature at 5 cm	.2443**
ST5MN=mean minimum soil temperature at 5 cm	.2031**
ST5MX=mean maximum soil temperature at 5 cm	.2700**
ST5DD=mean soil temperature at 5 cm degree days	.2439**
ST5DDRT=soil temperature at 5 cm degree days running total	-.2062**
ST10=mean soil temperature at 10 cm	.2319**
ST105MN=mean minimum soil temperature at 10 cm	.2056**
ST10MX=mean maximum soil temperature at 10 cm	.2530**
ST10DL=mean soil temperature at 10 cm degree days	.2317**
ST10DDRT=soil temperature at 10 cm degree days running total	-.2063**
PRCDAV=mean daily precipitation	.0957**
PRCMNDAV=mean minimum daily precipitation	.2435**
PRCMXDAV=mean maximum daily precipitation	.0917**
PRCTOT=total precipitation	.1916**
PRC.01=number of days precipitation events > 0.01 cm	.1863**
PRC.10=number of days precipitation events > 0.10 cm	.1796**
SM5=mean soil moisture at 5 cm	-.0159
SM5MN=mean minimum soil moisture at 5 cm	-.0549
SM5MX=mean maximum soil moisture at 5 cm	.0217
SM10=mean soil moisture at 10 cm	-.0326
SM10MN=mean minimum soil moisture at 10 cm	-.0997**
SM10MX=mean maximum soil moisture at 10 cm	.0519

** Indicates significant correlation ($p<0.001$)

Table 4.2. Comparison of p values (significance of F) for total mycorrhizae per gram of seedling root data (1985 through 1989) after multiple analysis of covariance (ANCOVA) using some of the highly correlated (p<.001) ambient parameters.

COVARIATE	SITE	YEAR	YEARxSITE
No Covariate	.335	.001	.279
PRCMNDAV[1/]	.349	.002	.336
PRCTOT	.733	.006	.411
ST5MX	.458	.001	.314
ST10MX	.547	.001	.314
ST5DD	.394	.001	.410

[1/]See Table 4.1 for key to abbreviations of ambient parameters.

Summary

Although there was a mean increase in mycorrhizae numbers from 1988 to 1989, no significant differences in mycorrhiza numbers per unit weight of seedling root among sites and among site and year interactions were detected using analysis of variance nor analysis of covariance. The use of individual ambient parameters, as covariates, in the analysis of covariance reduces the differences among sites and year by site interactions. It may be that refinements in the analysis by developing more appropriate temporal relationships between ambient data and seedling growth processes may further reduce differences among sites and possibly among years.

Detection limits calculated with three years of data prior to the operation of the ELF antenna (1985, 1986, 1987) indicated that an overall difference of approximately 10 to 15 percent would be necessary to recognize a significant difference among sites, and an overall difference of approximately 15 to 25 percent would be necessary to identify a significant difference among years and among site by year interactions. Additional years information is needed to fully assess the possible affects of ELF fields on mycorrhizal root production. With refinements of the ambient parameters as mentioned above and their application to the analysis, detection limits will probably decrease. Findings, thus far, support the proposal that mycorrhizal symbiosis between t_ee

roots and fungi can indeed be used as a sensitive indicator of subtle environmental changes.

Figure 4.1: Yearly and monthly comparisons of the total number of mycorrhizal root tips per gram of dry root (A) and the number of Type 3 mycorrhizal root tips per gram of dry soil (B).

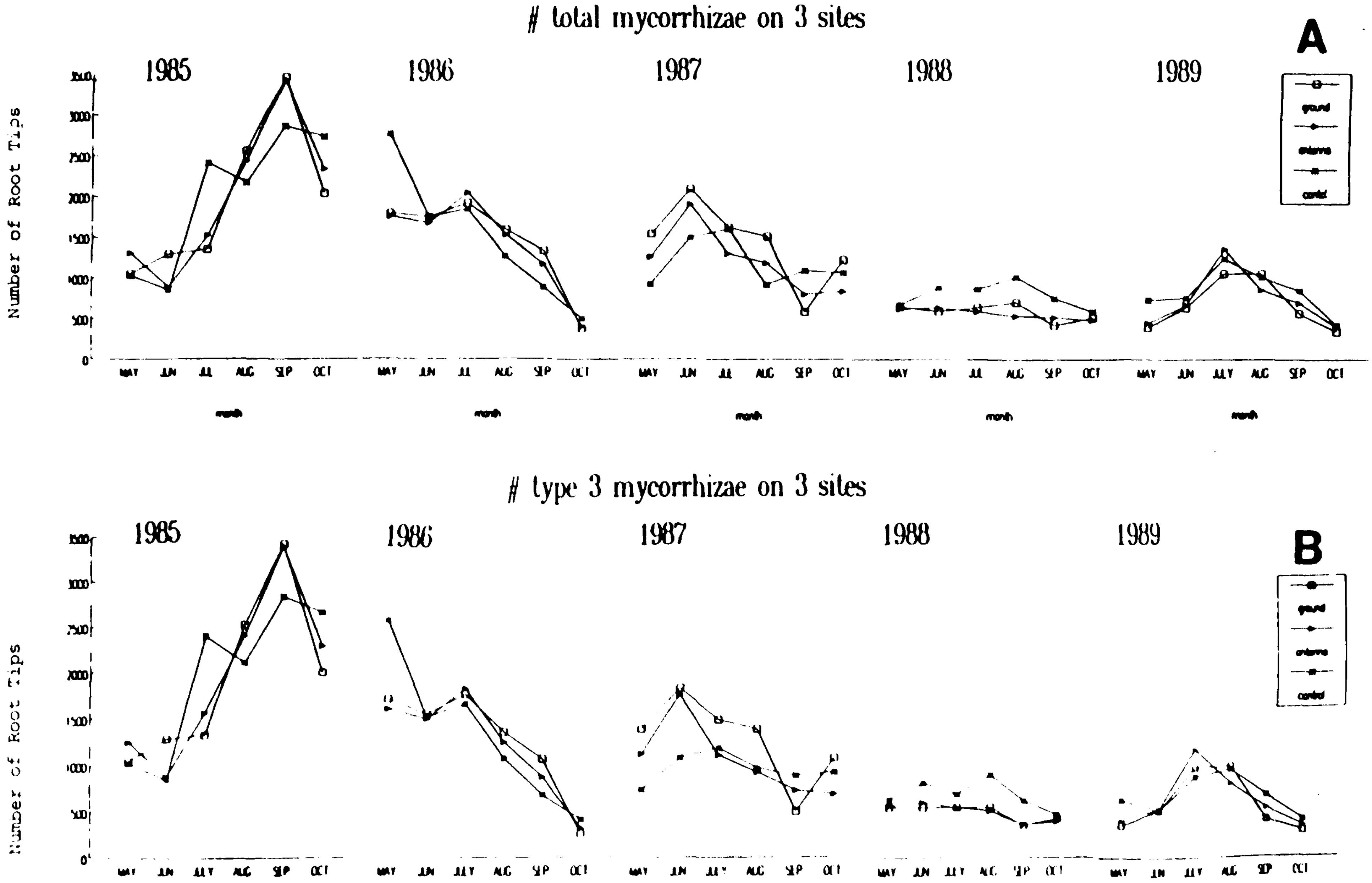
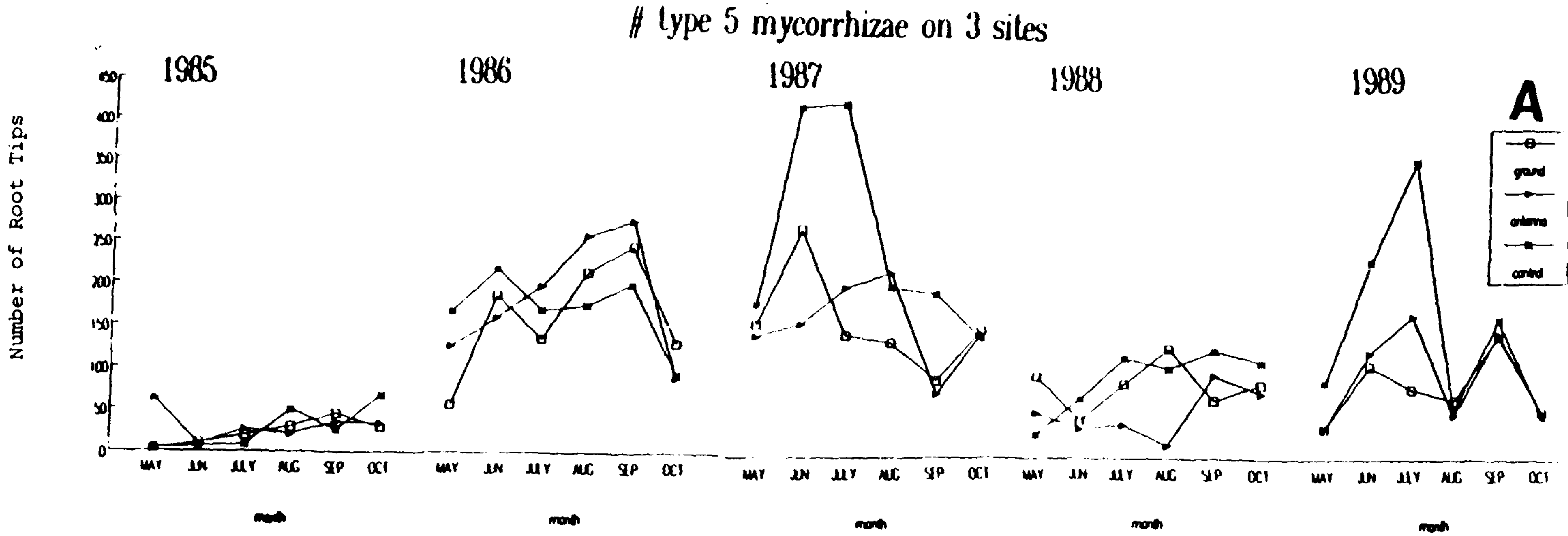
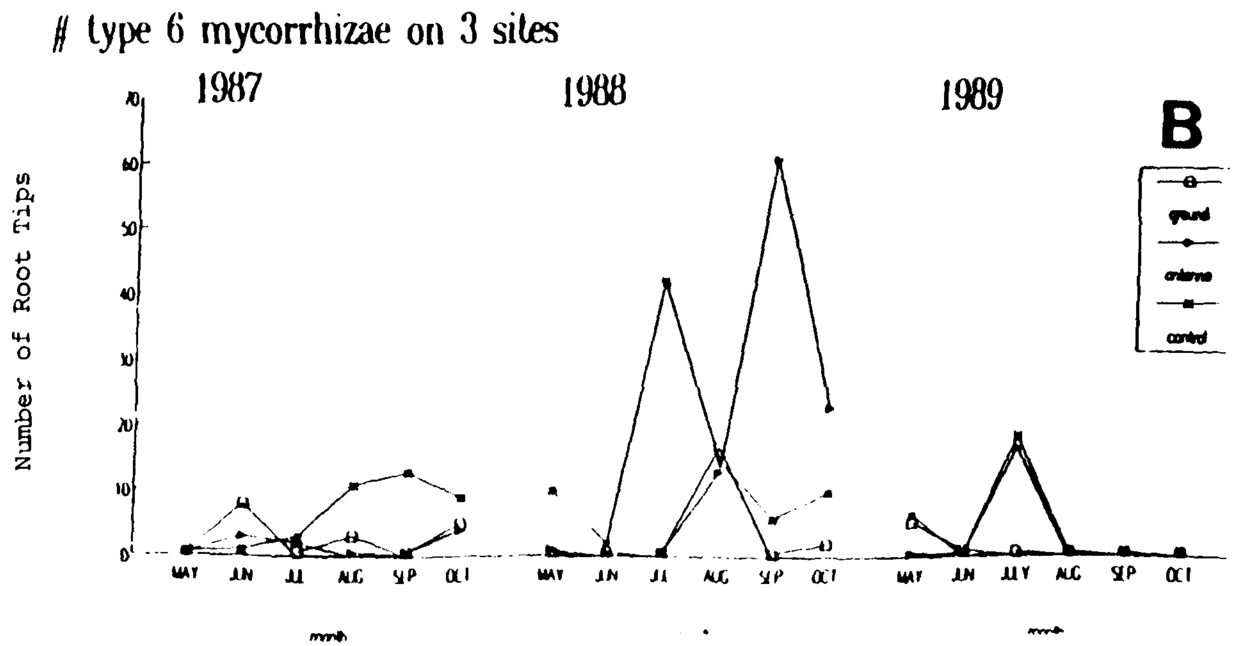


Figure 4.2: Yearly and monthly comparisons of the number of Type 5 mycorrhizal root tips per gram of dry root (A) and the number of Type 6 mycorrhizal root tips per gram of dry soil (B).





Element 5. LITTER PRODUCTION

Litter fall and decomposition is important in the transfer of nutrients and energy within a vegetative community. The sensitivity of foliage production to both tree physiological changes and non-independent external climatic conditions make it a good indicator of possible ELF field effects on trees. Since litter samples can be gathered at frequent intervals, they provide an estimate of change in canopy production. Additionally, leaf samples taken during the growing season for nutrient analysis and weight determination would monitor nutrient accumulation and subsequent nutrient translocation from the foliage to the branches prior to leaf fall. This physiological process is also sensitive to environmental stress and would be a potential indicator of ELF field effects.

The objective of this element is to obtain information on total litter weight and nutrient content, and foliar nutrient levels of northern red oak during the growing season on the antenna and control plots prior to the operation of the ELF communication system. Two overall null hypotheses will be tested in this study.

H_O: There is no difference in the total weight of litter fall (leaves, wood, and miscellaneous) before and after the ELF antenna becomes operational.

H_O: There is no difference in the foliar nutrient concentrations of northern red oak trees before and after the ELF antenna becomes operational.

Each year prior to an operational antenna (1984-1986), a baseline relationship of the ecological systems was determined whether there was any difference in the total weight of litter fall and foliar nutrient concentrations of northern red oak trees between the antenna and control site within a year.

The resulting ANOVA table for these analyses shown below (Table 5.1). Previous ELF annual reports have shown that no appreciable differences in these stand components were evident between these two sites prior to the onset of antenna operation.

Sampling and Data Collection

Five $1m^2$ meter litter traps are being used to monitor tree litter production on each permanent measurment plot at the antenna and the control sites. Litter was collected monthly during the summer and weekly after the onset of leaf fall in early September. Crown nutrient concentrations and translocation in northern red oak leaves are being examined by collecting foliage samples at both the antenna and control site during the summer months. An analysis of stem diameter data indicated that sampling trees of 15 cm, 21 cm and 32 cm

Table 5.1. ANOVA table for the analysis of litter components and foliar nutrients

Source of Variation	df	SS	MS	F
Plot	2	SS_P	MS_P	$MS_P/MS_{E(S)}$
Site	1	SS_S	MS_S	$MS_Y/MS_{E(S)}$
Error(s)	26	$SS_{E(S)}$	$MS_{E(S)}$	
Year	# years	SS_Y	MS_Y	$MS_Y/MS_{E(Y)}$
Site x year	(1)(#yrs-1)	SS_{SXY}		MS_{SXY} $MS_{SXY}/MS_{E(Y)}$

would adequately represent the distribution of red oak on each site. Three trees of each diameter were located adjacent to the permanent measurement plots at each site to minimize disturbance. Leaf samples were obtained from near the top of the crown using a 12 gauge shotgun with a full choke.

All litter and foliage samples were dried at 60°C in a forced draft oven. The litter was separated into leaves, wood, and miscellaneous categories and weighed. Leaf litter from a 0.25 m^2 compartment in each trap was separated by tree species. A representative subsample of ten leaves was taken from each foliage collection and weighed. All samples were ground to pass a 40 mesh sieve for subsequent N, P, K Ca and Mg analysis.

Progress

Litter weight

In 1988, the major litter fall in the ELF study area started between September 20 and September 27 and was completed by November 1 on both the antenna and control sites (Figure 6.1). Based on the previous 5-year average, this litter fall period began at a later date and continued longer into October (Figure 6.2a&b). As in past years, periodic litter fall amounts varied considerably between the antenna site and the control site at all collection times in the fall. These differences in weekly leaf fall are related to the variable tree species composition at each site. The leaf litter at the antenna site has a much higher proportion of red maple and big tooth aspen than the control site (Table 5.2). Oak leaves remain on the trees longer than the maple or aspen, and account for much of the litter fall variations between locations.

Figure 5.1

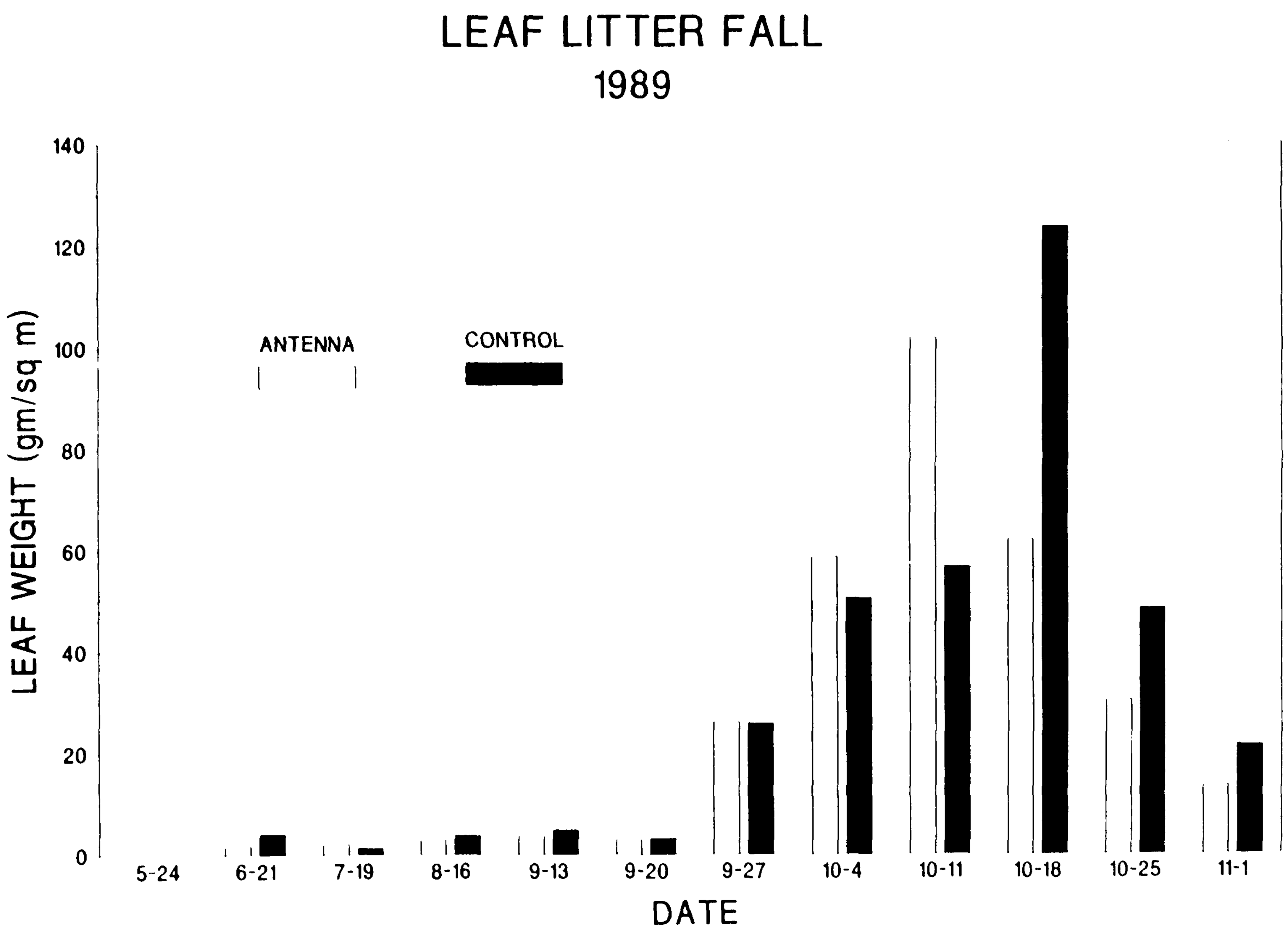
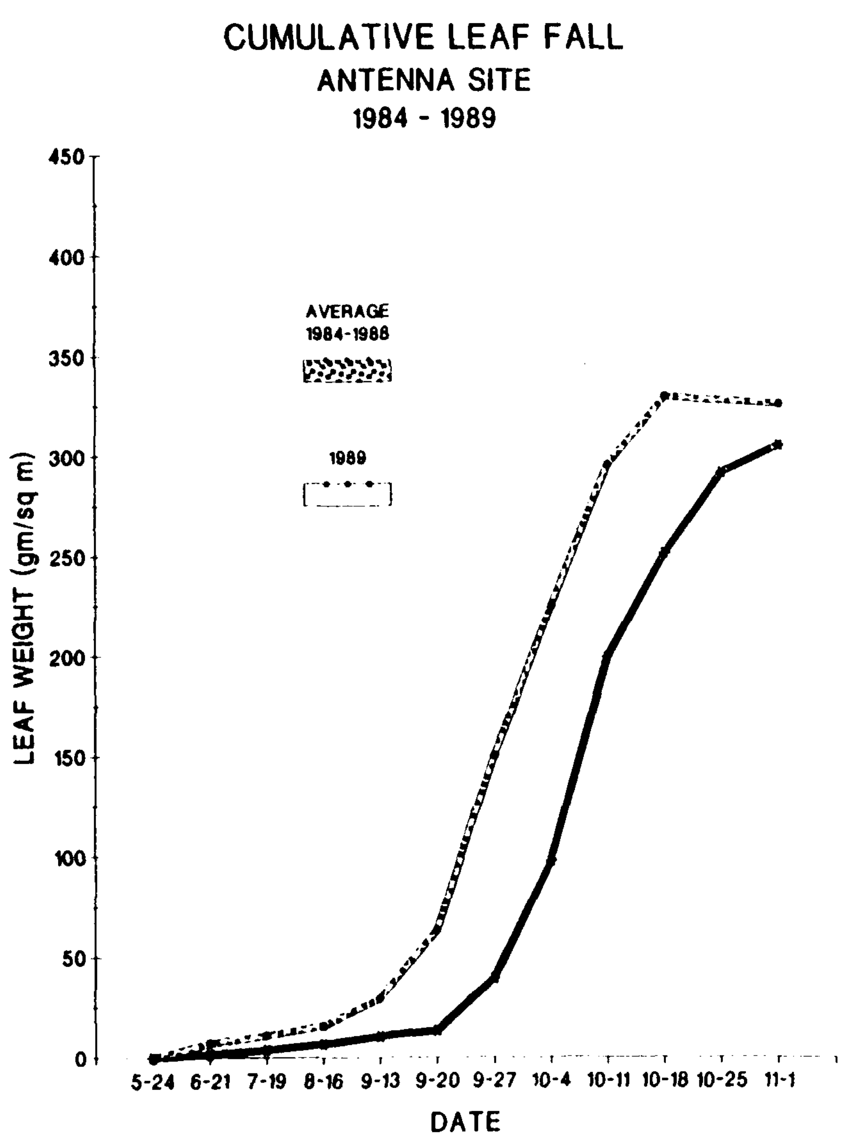
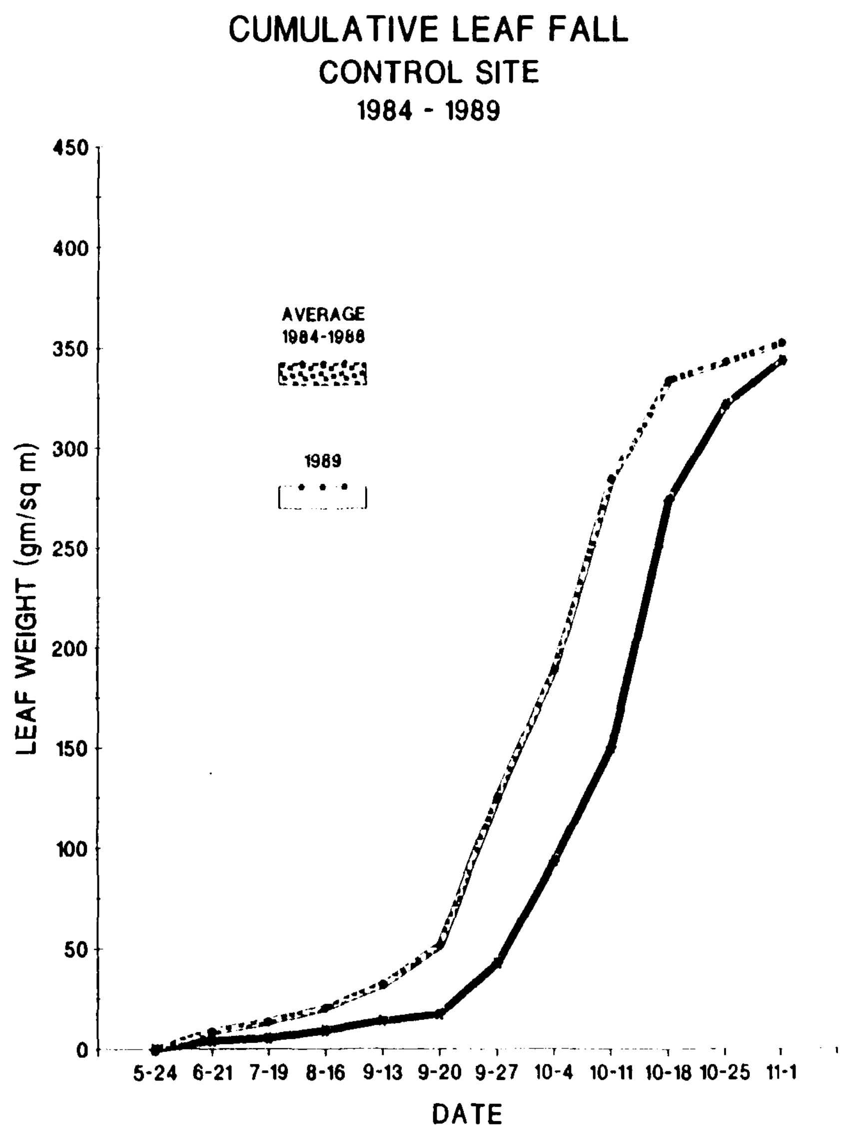

LEAF LITTER FALL
1989
LEAF WEIGHT (gm/sq m)
140
120
100
80
60
40
20
0
ANTENNA
CONTROL
5-24
6-21
7-19
8-16
9-13
9-20
9-27
10-4
10-11
10-18
10-25
11-1
DATE

Figure 5.



CUMULATIVE LEAF FALL
ANTENNA SITE
1984 - 1989
LEAF WEIGHT (gm/sq m)
450
400
350
300
250
200
150
100
50
0
AVERAGE
1984-1988
1989
5-24
6-21
7-19
8-16
9-13
9-20
9-27
10-4
10-11
10-18
10-25
11-1
DATE



CUMULATIVE LEAF FALL
CONTROL SITE
1984 - 1989
LEAF WEIGHT (gm/sq m)
450
400
350
300
250
200
150
100
50
0
AVERAGE
1984-1988
1989
5-24
6-21
7-19
8-16
9-13
9-20
9-27
10-4
10-11
10-18
10-25
11-1
DATE

Table 5.2. Leaf litter fall by tree species at the antenna and control sites: 1985-1989.

	Leaf Weight (g/m^2)					% of Total				
Tree Species	1985	1986	1987	1988	1989	1985	1986	1987	1988	1989
Antenna										
Red Maple	135	147	142	143	127	45	43	44	41	41
Red Oak	93	120	105	116	95	31	35	33	33	32
B. Aspen	45	52	46	56	18	15	15	14	17	6
Q. Aspen	1	1	2	3	2	<1	<1	<1	1	<1
Paper Birch	25	21	25	28	28	9	6	8	8	9
Red Pine	1	1	2	2	2	<1	<1	<1	<1	<1
Control										
Red Maple	42	55	47	41	48	14	17	16	13	14
Red Oak	227	266	208	230	223	73	69	69	71	65
B. Aspen	14	17	13	12	16	4	5	4	4	5
Q. Aspen	11	9	8	13	10	3	3	3	43	3
Paper Birch	19	22	26	26	20	6	6	8	8	6
Red Pine	0	0	0	0	0	0	0	0	0	0

Analysis of variance (ANOVA) using the six year litterfall results showed no significant site or site x year interaction differences between all litter component weights (Table 5.3). However, covariate analysis using stand and environmental variables that affect production was used to reduce litter fall variability among years, and improve detection limits between the antenna and control site. Similar to past years, soil and air temperature generally showed the highest correlations with litter production and gave the best results when used in the analyses of covariance (Table 5.4). The use of these covariates further reduced variability in litter fall among years and lowered the P values between sites (Table 5.5).

Results of these litter studies have shown that all three litter components could be used to study the effects of ELF fields on forest stands. However, the **a priori** detection limits for differences in foliage litter among years and between sites are much lower than with the wood and the miscellaneous litter fraction (Table 5.6), and so would be a more sensitive indicator of possible ELF effects. Given these limits and the results of the analysis of covariance, the lack of significance between the antenna and control sites for all three litter components indicate that the limited operational use of the ELF antenna in 1989 had no detectable effects on tree litter production.

Litter Nutrient Content

Total amounts of nutrients returned to the soil on each site reflect differences in site nutrient concentrations (Table 5.7). Average nutrient concentrations of the litter components for all tree species combined showed no site differences (Table 5.8 and 5.9). Covariate analysis using site and ambient factors listed in Table 5.10 was extremely useful in removing differences in litter nutrient concentrations among sites and years. However, significant site x year interactions for composite leaf litter P concentrations and miscellaneous litter Ca concentration could not be removed by covariate analyses. Similarly, significant site x year differences in P concentrations for oak and bigtoothed aspen, K concentration for hazelnut/birch, and Mg concentration for oak were still found after covariate analysis using environmental parameters (Tables 5.11 and 5.12).

Table 5.3. Total litter fall at the antenna and control sites: 1984-1988. Numbers in parentheses are standard deviations.

		Antenna (g/m^2)	Control (g/m^2)
Leaves			
1984		307 (66)	357 (102)
1985		347 (57)	352 (27)
1986		351 (49)	412 (87)
1987		332 (32)	319 (34)
1988		326 (45)	353 (53)
1989		305 (39)	344 (49)
	Average	328	356
Wood			
1984		44 (32)	54 (26)
1985		55 (31)	64 (33)
1986		43 (30)	58 (43)
1987		57 (38)	76 (38)
1988		53 (34)	62 (33)
1989		46 (40)	44 (33)
	Average	49	60
Miscellaneous			
1984		34 (24)	27 (14)
1985		52 (33)	45 (15)
1986		32 (8)	29 (11)
1987		33 (14)	28 (14)
1988		94 (64)	80 (35)
1989		97 (73)	64 (24)
	Average	57	46

Collection Period:
1984 - June 20, 1984 - Oct. 24, 1984
1985 - Oct. 25, 1984 - Oct. 23, 1985
1986 - Oct. 24, 1985 - Oct. 22, 1986
1987 - Oct. 23, 1986 - Oct. 21, 1987
1988 - Oct. 22, 1987 - Nov. 3, 1988
1989 - Nov. 4, 1988 - Nov. 1, 1989

Table 5.4. Correlations between litter component weight and the covariates selected for inclusion in the analysis of covariance.

	Litter Component		
Covariate	Foliage	Wood	Miscellaneous
Soil Temperature Degree Days at 5 cm (August 16-September 15)	--	.14	--
Soil Temperature Degree Days at 10 cm (June 16-July 15)	--	.15	.67
Air Temperature Degree Days (June 16-August 15)	-.26	--	--
Air Temperature Degree Days (through July)	--	--	.54

Table 5.5 Significance levels from the split plot analysis of covariance for litter components - 1985 to 1989

Factor	Foliage	Wood	Miscellaneous
	-----------p values----------		
Site	0.89	0.89	0.56
Years	0.01	0.49	0.00
Site x Years	0.26	0.78	0.55

Table 5.6. Detection limits of litter component weights between treatment sites and between years.*

Litter Component	Sites		Years	
	g/m^2	%	g/m^2	%
Foliage	66.3	19.0	34.5	9.9
Wood	32.7	55.9	16.6	28.5
Miscellaneous	30.5	62.3	16.1	32.8

*The detection limits given are for differences at p=0.05 on covariate adjusted means.

To further investigate these significant site x year interactions, SNK multiple range tests were performed using covariate adjusted means to evaluate whether nutrient concentrations had changed in response to ELF antenna operation starting in 1987 (Figure 5.3). The graphs show that in all cases, significant litter nutrient concentration differences existed between sites and years prior to the antenna operation. In addition, covariate analyses were run using both environmental measurements and the ELF field exposure data for 1989 (Appendix A). The inclusion of the various ELF field values did not alter or remove the site x year interactions found for litter nutrient concentrations. Since most leaf litter nutrient concentration detection levels are well below ten percent of the mean (Tables 5.13 and 5.14), these results indicate that differences in litter nutrient concentrations between the antenna and the control site can not be attributed to the low level ELF fields generated since 1987.

Foliage analyses

Nutrient concentrations in red oak foliage show considerable variability between the antenna and the control sites, but these generally reflect the nutrient status of the two sites before antenna transmissions began (Table 5.15). Results from covariate analyses using soil and climatic data showed there were significant site x year interactions for N, P, and K that could not be explained using the covariates tested (Table 5.16). Similar results were found for site x month interactions. Multiple range tests were used to

Table 5.7. Average nutrient content of litterfall at the antenna and control sites: 1985-1987.

	Antenna				Control			
	1985	1986	1987	1988	1985	1986	1987	1988
	(kg/ha)							
Foliage								
N	26.4	26.4	26.2	19.9	28.1	19.9	24.9	21.5
P	4.6	4.2	4.4	4.6	10.0	4.6	4.0	5.3
K	9.9	10.1	9.0	12.4	13.6	10.5	13.5	18.0
Ca	36.0	33.1	40.6	38.1	35.7	37.2	44.1	40.2
Mg	5.7	5.5	6.1	5.5	5.6	5.8	6.0	6.4
Wood								
N	3.2	2.7	2.3	2.2	0.4	3.3	2.7	3.0
P	0.3	0.3	0.2	0.3	4.0	0.[illegible]	0.2	0.4
K	0.5	0.4	0.3	0.7	0.9	0.8	0.5	0.8
Ca	6.8	4.3	5.5	4.7	9.0	7.5	6.3	9.4
Mg	0.4	0.3	0.3	0.3	0.6	0.5	0.3	0.4
Miscellaneous								
N	7.1	3.4	12.3	12.0	5.1	3.7	6.6	7.8
P	0.8	0.3	1.3	1.4	0.9	0.3	0.7	1.0
K	2.8	1.0	1.9	5.7	1.6	0.7	1.4	6.3
Ca	3.0	2.0	8.8	5.0	5.6	3.1	9.9	4.0
Mg	0.5	0.3	1.0	0.8	0.4	0.2	0.7	0.7
Total								
N	36.7	32.5	40.8	34.1	37.2	26.9	24.2	32.3
P	5.7	4.8	5.9	6.3	11.3	5.3	4.9	6.7
K	13.2	11.5	11.2	18.8	16.1	12.0	15.4	22.8
Ca	45.8	39.4	54.9	47.8	50.3	47.8	60.3	53.6
Mg	6.6	6.1	7.4	6.6	6.6	6.5	7.0	7.5

Values in rows denoted by different letters are significantly different at the $p=0.05$ level.

Table 5.8. Average nutrient concentrations of litter components on the antenna and control sites: 1985-1988. Numbers in parentheses are standard deviations.

	Antenna	Control
	(%)	
Foliage		
N	0.78 (0.14)	0.71 (0.09)
P	0.13 (0.01)	0.18 (0.08)
K	0.29 (0.07)	0.37 (0.03)
Ca	1.09 (0.16)	1.14 (0.13)
Mg	0.17 (0.28)	0.17 (0.10)
Wood		
N	0.54 (0.10)	0.54 (0.14)
P	0.06 (0.01)	0.57 (0.02)
K	0.10 (0.05)	0.14 (0.06)
Ca	1.09 (0.19)	1.24 (0.24)
Mg	0.06 (0.01)	0.75 (0.19)
Miscellaneous		
N	1.24 (0.25)	1.08 (0.23)
P	0.13 (0.03)	0.14 (0.05)
K	0.34 (0.16)	0.26 (0.11)
Ca	0.72 (0.19)	1.19 (0.28)
Mg	0.10 (0.02)	0.09 (0.06)

Table 5.9. **Average nutrient concentrations of tree litter on the antenna and control sites: 1985-1988. Numbers in parentheses are standard deviations.**

	Antenna	Control
	(%)	
Northern Red Oak		
N	0.73 (0.19)	0.65 (0.09)
P	0.13 (0.02)	0.16 (0.06)
K	0.30 (0.07)	0.38 (0.04)
Ca	0.99 (0.08)	1.07 (0.09)
Mg	0.11 (0.01)	0.15 (0.02)
Paper Birch		
N	0.81 (.014)	0.78 (0.10)
P	0.15 (0.02)	0.18 (0.03)
K	0.40 (0.08)	0.55 (0.09)
Ca	1.45 (0.21)	1.24 (0.16)
Mg	0.26 (0.03)	0.29 (0.02)
Big Toothed Aspen		
N	0.75 (0.07)	0.68 (0.12)
P	0.10 (0.03)	0.14 (0.05)
K	0.32 (0.09)	0.49 (0.12)
Ca	1.33 (0.18)	1.52 (0.16)
Mg	0.26 (0.03)	0.21 (0.03)
Red Maple		
N	0.47 (0.05)	0.50 (0.10)
P	0.15 (0.02)	0.17 (0.03)
K	0.21 (0.08)	0.32 (0.10)
Ca	1.06 (0.10)	1.21 (0.05)
Mg	0.18 (0.02)	0.19 (0.01)

Table 5.10. Covariates used in covariate analyses of litter nutrient concentrations among sites and year.

Soil Nutrients in September		
Soil N	-	a
Soil P	-	b
Soil K	-	c
Soil Ca	-	d
Soil Mg	-	e
Air temperature degree days		
in September	-	f
in October	-	g
Air temperature degree days running total		
to the end of September	-	h
to the end of October	-	i
Air temperature		
in September	-	j
in October	-	k
Soil temperature at 5 cm		
in September	-	l
in October	-	m
Soil temperature at 10 cm		
in September	-	n
in October	-	o
Soil temperature degree days at 5 cm running total		
to the end of September	-	p
to the end of October	-	q
Soil temperature degree days at 10 cm		
in September	-	r
in October	-	s
Soil temperature degree days at 5 cm		
in September	-	t
in October	-	u

Table 5.11. Results of covariate analyses of site and year differences in litter component nutrient concentration.

	N	P	K	Ca	Mg
	--------	--------	p value	--------	--------
Leaf	--	(c)*	--	(f)	(e)
Site	.183	.588	.120	.235	.489
Year	.165	.103	.001	.005	.064
Year x Site	.511	.000	.277	.281	.256
Wood	(ps)	(s)	(c)	(d)	(c)
Site	.655	.932	.551	.049	.753
Year	.864	.377	.020	.130	.311
Year x Site	.697	.742	.969	.235	.327
Miscellaneous	(cq)	(bc)	(h)	(dn)	(am)
Site	.058	.363	.086	.143	.099
Year	.184	.159	.000	.001	.810
Year x Site	.093	.127	.122	.030	.356

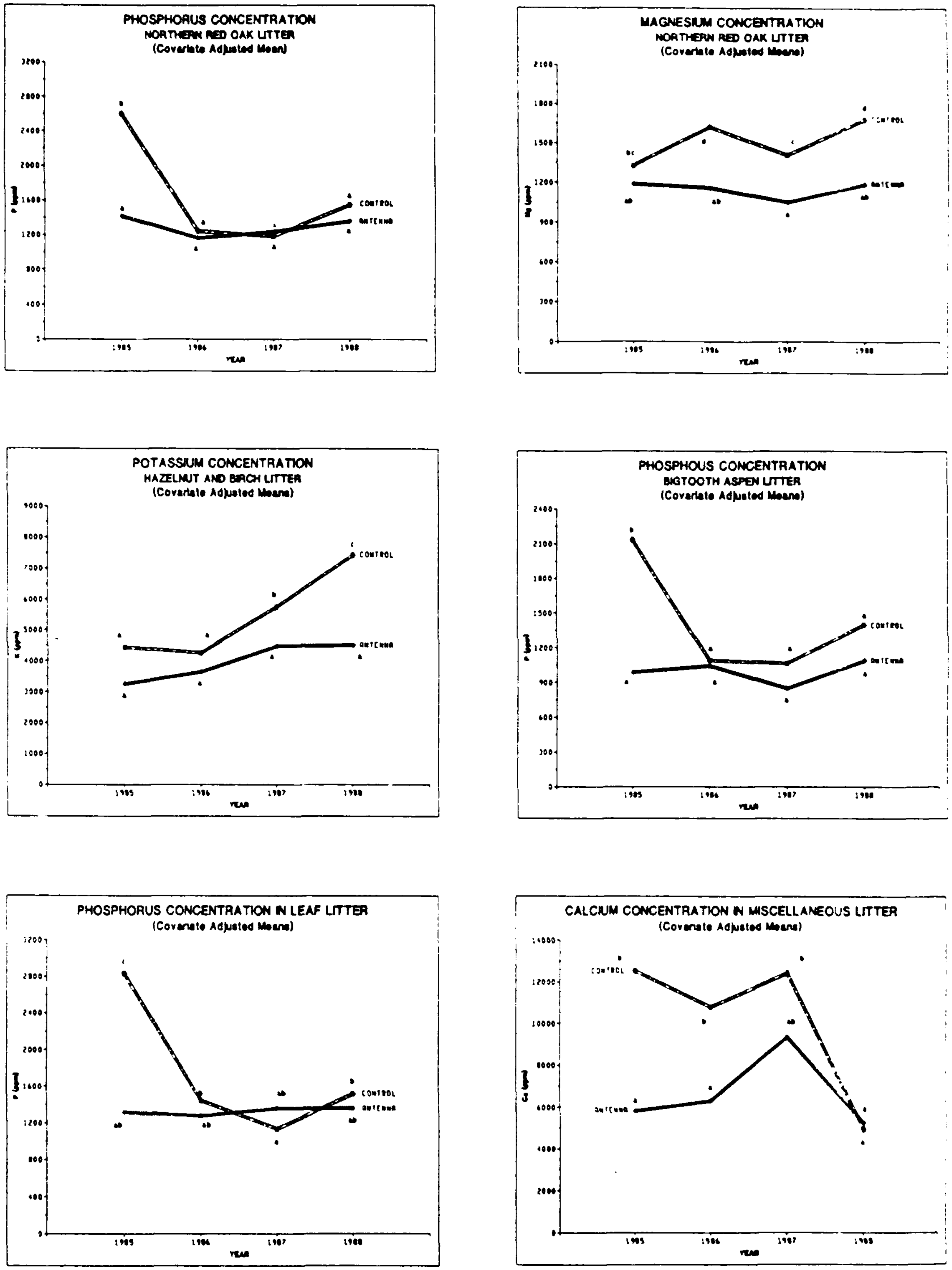
*Variables used in COANOVA (see Table 6.10).

Table 5.12. Results of covariate analyses of site and year differences in leaflitter nutrient concentrations by species.

	N	P	K	Ca	Mg
	p value				
Northern Red Oak	--	(cf)	(cf)	(bh)	(ei)
Site	.297	.847	.538	.695	.090
Year	.012	.001	.174	.000	.005
Year x Site	.766	.000	.614	.263.	.008
Hazelnut and Paper Birch	(ab)	(cf)	(ah)	(kh)	(ah)
Site	.734	.966	.354	.848	.629
Year	.030	.159	.023	.000	.293
Year x Site	.942	.073	.035	.238	.344
Big Toothed Aspen	(bq)	(cde)	(dg)	(der)	(cdg)
Site	.395	.583	.188	.862	.199
Year	.770	.197	.064	.001	.021
Year x Site	.155	.010	.246	.258	.158
Red Maple	(cgh)	(l)	(ci)	(hit)	--
Site	.619	.585	.035	.181	.209
Year	.103	.065	.000	.327	.058
Year x Site	.163	.129	.489	.249	.482

*Variables used in COANOVA (see Table 6.10.).

Figure 5.3



PHOSPHORUS CONCENTRATION
NORTHERN RED OAK LITTER
(Covariate Adjusted Mean)
CONTROL
ANTENNA
YEAR
MAGNESIUM CONCENTRATION
NORTHERN RED OAK LITTER
(Covariate Adjusted Means)
CONTROL
ANTENNA
YEAR
POTASSIUM CONCENTRATION
HAZELNUT AND BIRCH LITTER
(Covariate Adjusted Means)
CONTROL
ANTENNA
YEAR
PHOSPHOUS CONCENTRATION
BIGTOOTH ASPEN LITTER
(Covariate Adjusted Means)
CONTROL
ANTENNA
YEAR
PHOSPHORUS CONCENTRATION IN LEAF LITTER
(Covariate Adjusted Means)
CONTROL
ANTENNA
YEAR
CALCIUM CONCENTRATION IN MISCELLANEOUS LITTER
(Covariate Adjusted Means)
CONTROL
ANTENNA
YEAR

Table 5.13. Detection limits for litter nutrient concentrations by component.*

Component	Site		Year	
	ppm	% of mean	ppm	% of mean
Leaf				
Ca	962	8.6	275	2.5
Mg	171	9.9	59	3.4
K	480	14.7	280	8.6
N	480	6.4	878	11.7
P	167	10.7	76	4.9
Wood				
Ca	650	4.8	330	2.8
Mg	75	10.8	91	13.2
K	161	13.7	278	23.7
N	656	12.1	777	14.3
P	79	14.0	89	15.8
Misc.				
Ca	2025	21.4	1183	12.5
Mg	80	8.6	56	6.0
K	400	13.1	t512	16.8
N	871	7.5	1319	11.4
P	173	13.0	104	7.8

*The detection limits given are for differences at p=0.05 on covariate adjusted means.

Table 5.14. Detection limits for leaf litter nutrient concentrations by species.*

Species	Site ppm	Site % of mean	Year ppm	Year % of mean
Nortnern Red Oak				
N	1076	14.6	795	10.1
P	116	11.3	68	4.8
K	306	9.3	228	6.9
Ca	326	3.3	206	2.1
Mg	135	10.5	39	3.0
Hazelnut and Birch				
Ca	1574	11.6	352	2.6
Mg	245	8.9	107	3.9
K	403	9.4	307	7.1
N	831	10.0	341	4.1
P	193	11.9	116	7.2
Big Tooth Aspen				
Ca	1409	9.7	368	2.5
Mg	234	10.0	68	2.9
K	901	22.8	343	8.7
N	354	4.9	365	5.1
P	295	25.0	136	11.5
Red Maple				
Mg	118	6.5	73	4.0
Ca	414	3.7	454	4.1
K	220	9.6	269	11.8
N	435	8.8	298	6.0
P	130	8.3	119	7.6

*The detection limits given are for differences at p=0.05 on covariate adjusted means.

evaluate these site differences (Figure 5.4). These analyses showed that in all cases, significant site x year and site x month differences occurred prior to the antenna operation beginning in 1987.

Table 5.15. Northern Red Oak foliage nutrient concentration for antenna and control sites for 1985 to 1988.

	Antenna				Control			
	1985	1986	1987	1988	1985	1986	1987	1988
	(%)				(%)			
N	2.04	1.88	1.89	1.73	1.80	1.98	1.78	2.09
P	0.18	0.20	0.19	.16	0.17	0.20	0.18	.19
K	0.87	0.82	0.75	1.01	0.95	1.02	0.18	1.02
Ca	0.71	0.73	0.65	.76	0.68	0.80	0.64	.79
Mg	0.13	0.14	0.15	.16	0.13	0.15	0.15	.16

A factor in evaluating foliage nutrient concentrations is the weight of individual leaves. Consequently, an analysis of variance was conducted on average yearly leaf weights on the antenna and the control sites (Table 5.17) No significant site, month, year, and diameter interactions were found.

In contrast to the litter nutrient results, ELF field measurments were not used as a covariate for red oak foliage nutrient concentrations. Due to a lag in laboratory nutrient analyses, only the foliage samples collected up to 1988 have been processed. Since the antenna was operating sporatically in 1988, it was felt that little would be gained by ELF antenna operations in the covariate analyses. However, ELF field effects will be included in the analysis of 1989 foliage next year.

Since good covariates are presently lacking for the covariate analysis of foliage nutrient content, detection limits are relatively high (Table 5.18). Detection limits are generally under ten percent for yearly differences, but over ten percent between sites. Thus, changes in tree nutrient translocation and cycling as affected by the ELF electromagnetic fields need to be relatively large to be detected by these analyses.

Figure 5.4

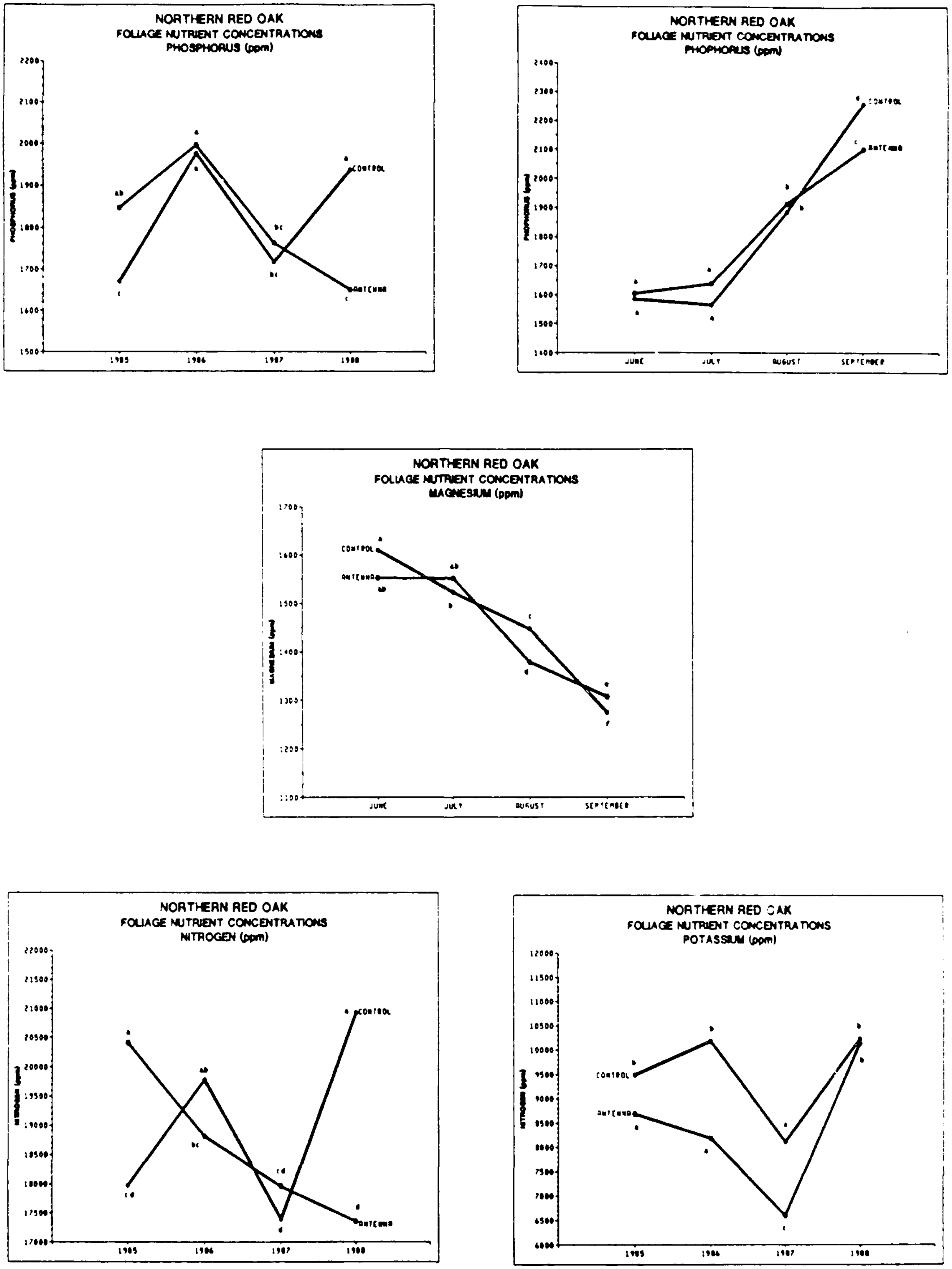

NORTHERN RED OAK
FOLIAGE NUTRIENT CONCENTRATIONS
PHOSPHORUS (ppm)
CONTROL
ANTENNA
1985
1986
1987
1988
NORTHERN RED OAK
FOLIAGE NUTRIENT CONCENTRATIONS
PHOPHORUS (ppm)
CONTROL
ANTENNA
JUNE
JULY
AUGUST
SEPTEMBER
NORTHERN RED OAK
FOLIAGE NUTRIENT CONCENTRATIONS
MAGNESIUM (ppm)
CONTROL
ANTENNA
JUNE
JULY
AUGUST
SEPTEMBER
NORTHERN RED OAK
FOLIAGE NUTRIENT CONCENTRATIONS
NITROGEN (ppm)
CONTROL
ANTENNA
1985
1986
1987
1988
NORTHERN RED OAK
FOLIAGE NUTRIENT CONCENTRATIONS
POTASSIUM (ppm)
CONTROL
ANTENNA
1985
1986
1987
1988

Table 5.16. Results of covariate analyses for differences in foliage nutrient concentration.

	N (1)*	P (2)	K (3)	Ca (4)	Mg (5)
	p values				
Site	.311	.396	.040	.814	.983
Tree Diameter	.448	.193	.028	.160	.053
Site x Diameter	.585	.924	.172	.106	.136
Year	.000	.000	.000	.000	.000
Year x Site	.000	.000	.002	.133	.421
Year x Diameter	.501	.167	.020	.581	.427
Year x Site x Diameter	.242	.729	.655	.819	.522
Month	.000	.000	.000	.000	.000
Month x Site	.290	.001	.245	.786	.008
Month x Year	.000	.000	.000	.003	.002
Month x Year x Site	.106	.018	.000	.095	.195

* Covariates used

1 Average maximum air temperature, soil moisture at 10 cm, soil temperature degree days at 10 cm - running total
2 Air temperature degree days
3 Soil K and Mg, soil temperature degree days at 10 cm
4 Soil temperature degree days at 10 cm - running total
5 Average maximum air temperature, soil moisture at 5 cm, soil temperature degree days at 5 cm

Table 5.17. Analysis of variance results testing for differences in the average weight of ten leaf samples by site, tree diameter and sampling time (1985-89).

	p value
Site	.884
Diameter	.554
Site x Diameter	.199
Year	.000
Year x Site	.500
Year x Diameter	.151
Year x Diameter x Site	.345
Month	.004
Month x Site	.691
Month x Year	.087
Month x Year x Site	.620

Table 5.18. Detection limits for Northern Red Oak foliage nutrient concentrations.*

	Site		Year	
	ppm	% of mean	ppm	% of mean
N	844	4.5	1532	8.2
P	228	15.2	177	9.7
K	1242	14.5	982	9.3
Ca	1684	23.7	792	11.1
Mg	342	22.5	108	7.5

*The detection limits given are for differences at $p=0.05$ on covariate adjusted means.

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APPENDIX A

Electromagnetic field measures and correspondence

Table 1 Estimated average yearly exposure levels by plot for the ground site for 1985, 1986, 1987, and 1988.

	1985	1986	1987	1988
60 H				
Transverse (V/m)				
Plot 1	0.0000	0.0000	0.0032	0.0032
Plot 2	0.0000	0.0000	0.0002	0.0002
Plot 3	0.0000	0.0000	0.0018	0.0018
Longitudinal (mV/m)				
Plot 1	4.1956	4.1956	37.9685	7.3923
Plot 2	0.2851	0.2851	0.9544	0.4879
Plot 3	2.2794	2.2794	19.5667	4.0091
Magnetic Flux (m/G)				
Plot 1	0.0173	0.0173	0.0686	0.1162
Plot 2	0.0015	0.0015	0.0047	0.0067
Plot 3	0.0096	0.0096	0.0373	0.0625
76 H				
Transverse EW (V/m)				
Plot 1	0.0000	2.9190	2.9190	22.7808
Plot 2	0.0000	0.0727	0.0727	0.5531
Plot 3	0.0000	1.5243	1.5243	11.8892
Longitudinal EW (mV/m)				
Plot 1	0.0000	2654.3720	3421.6820	7689.0220
Plot 2	0.0000	6.5540	23.4050	184.5830
Plot 3	0.0000	1356.9390	1756.5230	4011.8400
Magnetic Flux EW (m/G)				
Plot 1	0.0000	5.0668	10.9406	55.3601
Plot 2	0.0000	0.2231	0.5958	2.8562
Plot 3	0.0000	2.6934	5.8717	29.6332

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26 January 1990

Dr. Glenn Mroz
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Dear Dr. Mroz:

The purpose of this letter is to provide you with documentation of the annual ELF electromagnetic (EM) field measurements made by IITRI at your study sites on 19 September and 11 and 12 October 1989. EM measurement data from previous years and a brief summary of the Michigan Transmitter Facility (MTF) operations for 1989 are also included.

Study Sites

This year, EM measurements were made at 45 locations at the study sites listed in Table 1. Measurement positions within each study site are diagrammed in Figures 1 through 5. Please check these figures for accuracy. All measurement points characterized from 1985 through 1988 were remeasured in 1989. In addition, five measurement locations were added at the antenna test site and eight locations were added at the ground test site in order to characterize the EM field profiles across these study areas.

MTF Operations - 1989

A brief summary of MTF operations for 1989 is provided in Table 2. It is intended to provide an overview of the average and cumulative periods of ELF EM exposure at your study sites during 1989. As day-to-day variations in the MTF schedule were extensive, this summary can not be used to define the antenna operating conditions for specific points in time.

For the first four months of 1989 the MTF operated intermittently during the weekday hours of 8am to 4pm EST, and was OFF at other times. Only single antenna operation (either north/south or east/west) at 75 amperes was employed, with unmodulated signals at 44 Hz or 76 Hz.

During the first two weeks of May, the MTF conducted testing and tuning activities at 150 amperes using one or both antennas. Operation was between 8am and 5pm EDT and totaled one to eight hours/day. Various frequencies from 40 Hz to 80 Hz were employed with both unmodulated and modulated signals.

The MTF began standard 150 ampere operation with both antennas on 14 May, operating continuously from 4pm to 8am EDT weekdays and all day on weekends. During these periods the operating frequency was typically 76 Hz, either modulated or unmodulated. On weekdays beginning the same date, the MTF usually operated intermittently from 8am to 4pm EDT. During these working hours one or both antennas were operated at 150 amperes and frequencies of 44 Hz or 76 Hz. Intermittent operation ranged from near zero up to eight hours/day.

The MTF became an operational Navy communications facility on 7 Oct. Since that time it has operated continuously, with the exception of normally scheduled maintenance periods from 9am to 2pm EDT on Tuesdays and Thursdays. Normal operating parameters are 150 amperes on both antennas and a modulated signal centered at 76 Hz.

At this time, a computer database of MTF operating times and conditions for 1989 is still in preparation. A monthly and an annual summary of the hours of MTF operation by antenna condition will be included in the 1989 EM Field Measurements and Engineering Support report. In the meantime, if you require more detailed operating times data for a specific period, we can send you a copy of the monthly operating summaries as provided to IITRI by the Navy.

EM Measurement Protocol

Measurements of 76 Hz EM fields were conducted in 1989 at all study sites with antenna currents of 150 amperes. This is the first year that EM measurements were made under full-power MTF operation. Ambient 60 Hz EM fields were also measured at the control and leaf sampling sites. Ambient fields could not be measured at either test site because the 60 Hz fields were masked by the EM fields generated by the east/west antenna under modulated signal operation.

Three types of EM fields were characterized at each measurement point: transverse (or air) electric field, longitudinal (or earth) electric field, and magnetic flux density. For each of the fields, a set of orthogonal measurements were made and reduced to a single magnitude by vector addition. EM field intensities were determined under the following conditions:

1) The ambient 60 Hz fields were measured with both antennas operating at 150 amperes, standard phasing, and an unmodulated signal.

2) The 76 Hz fields from the MTF were measured with both antennas operating at 150 amperes, standard phasing, and either a modulated or an unmodulated signal.

Measurement locations within your study sites were initially chosen to be at plot corners and along plot boundaries, based on the intermediate size and rectangular shape of the site plots. This served to bracket the range of EM field intensities over the study ares. However, because the test plots cross either an antenna or ground element, they experience ranges of EM field exposures that typically span one to two orders of magnitude. To better characterize the test sites in 1989, EM field profiles were measured along transects perpendicular to the rights-of-way. Meaqsurement points were typically evenly-spaced on the profiles, but extra points were added at locations of localized field nulls and maxima near the overhead and buried wires.

60 Hz EM Fields

60 Hz EM field measurement data for 1983 through 1989 are presented in Tables 3-5. As previously stated, ambient field intensities could not be measured at your test sites in 1989 because of modulated signal operation of the MTF. The 60 Hz ambient field intensities measured at your control and leaf collection sites are consistant with values measured in previous years.

76 Hz EM Exposures - 1989

The 76 Hz EM field measurement data taken during the 1989 annual EM survey, along with data from earlier years, are presented in Tables 6-8. All field measurements were made and are presented as vector sum magnitudes. The antenna currents at which measurements were made in each year are given in the column headings of the tables. The 1989 measurements were made with 150 ampere antenna currents, the predominent MTF operating current since 4 May. The EM exposures at your study sites for the period prior to 4 May can be estimated either by using the 75 ampere antenna current measurement data from 1988, or by taking one-half of the value of the 1989 150 ampere data.

Plots of the 76 Hz EM field profiles for the antenna and ground test sites are presented in Figures 6 through 9. The EM field intensities at any point in the test plots can be estimated from the appropriate EM field profiles, given the straight-line distance of the point to the antenna or ground wire. However, the accuracy of such estimates may be limited by several factors, as discussed below.

At the ground site, both the magnetic field (Figure 9) and the transverse (air) electric field (Figure 8) gradients conform well to theoretical prediction. The slight dip in the magnetic field contour over the buried ground wire is likely the result of partial cancellation between the field generated by the overhead feed wire and that from the buried ground wire. The longitudinal (earth) electric field contour (Figure 9) shows the expected deep null directly over the buried ground wire and the field maxima nearby on either side. The symmetrical and consistant roll-off of the longitudinal electric field contour indicates that the bulk soil conductivity at this site is fairly uniform over a large area. Thus, the accuracy of estimates of the EM fields at the ground test site will be primarily limited by the accuracy of locating the points of interest with respect to the buried ground wire. This will be especially true for points close to the wire where the field magnitudes change rapidly over small distances.

At the antenna site, the magnetic field (Figure 7) also conforms well to theory. Magnetic field estimates based on the measured profile should be very good for distances of 10 m or greater from the overhead wire. Along the southeastern edge of the pine plantation some variation from the measured profile may occur because changes in terrain elevation close to the wire will affect the absolute distance to the wire, and therefore the field magnitude. The air electric field (Figure 6) behaves predictably in the pine plantation and air field estimates there should be as accurate as those for the magnetic field. Within the hardwood stands, however, the vertical component of the air electric field produced by the overhead wire is greatly attenuated. Here the air field is primarily horizontal and is generated by the earth electric field. As a result, the air electric field in the stands is less predictable and the accuracy of field estimates is markedly reduced.

The profile of the longitudinal (earth) electric field intensity across the antenna site is quite irregular (see Figure 7). Indeed, the field's intensity does not decrease with distance from the antenna as anticipated, but generally increases across the site. The most plausible explanation for this unusual profile is that the bulk conductivity of the soil is highly variable over both the pine plantation and pole stand. One would, therefore, have low confidence in any estimates of the earth electric field intensities. Should estimates of

the longitudinal electric field intensities be required at this site, it is recommended that they be derived by linear interpolation between the nearest measured points and not from the measured profile provided with this letter.

We have forwarded estimated field intensities for 150 ampere antenna operation in previous letters and reports. With these 1989 data, you now have measured values for the 76 Hz EM exposures at your study sites for full power MTF operation. EM exposure ratios have not been calculated by IITRI for 1989 or the past two years because the primary function of the ratios was to serve as guidelines for site selection. However, we suggest that you compute the exposure ratios using the measured 150 ampere data to verify that the EM ratios between paired study sites, as well as EM variations and gradients across sites, are consistent with the goals of your study. We would appreciate information on your plans for incorporating the EM exposure measurements into your analyses, and will be happy to assist with the calculation of EM exposure ratios. Software copies of the EM data tables will be made available for use in analyses or inclusion in your annual report.

<u>1990 Schedule</u>

As an operational communications system, the MTF is expected to continue full-time 150 ampere operation except for scheduled maintenance. The annual EM measurements for 1990 have not been scheduled, but will likely be in the August-October period. If you require any special engineering assistance or EM measurements in addition to those normally conducted or already discussed above, please inform us immediately so that these activities may be scheduled. Please contact me or Jack Zapotosky regarding the questions and concerns raised in this letter.

Sincerely,

IIT RESEARCH INSTITUTE

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JRG:bjm

cc: Dr. J. Bruhn, MTU
JEZapotosky
RDCarlson/File
DPHaradem
RGDrexler

TABLE 1. SITE NO. CROSS-REFERENCE
Upland Flora and Soil Microflora Studies

IITRI Site No.	Investigator's Site Name	Location				
		Township	:	Range	:	Section(s)
4T2	Martell's Lake (Overhead): ML	T45N	:	R29W	:	28
4T4	Martell's Lake (Buried): EP	T45N	:	R29W	:	28
4C1	Paint Pond Road Control	T41N	:	R32W	:	3
4S1	Red Maple Leaf Collection	T55N	:	R35W	:	21
4S2	Oak Leaf Collection	T41N	:	R32W	:	3
4S3	Pine Needle Collection	T54N	:	R34W	:	5

TABLE 2. MTF 1989 OPERATIONS SUMMARY

Period	Operating Times And Conditions
1 Jan. thru 17 Mar.	Intermittent weekday operation, 8am - 4pm EST. Single antenna operation at 75 amperes. 44 Hz or 76 Hz, unmodulated.
18 Mar. thru 3 May	Both antennas OFF except for 12 hours of operation at 75 amperes.
4 May thru 13 May	Began 150 ampere tuning and testing. Intermittent operation 8am - 5pm EDT. Single antenna operation at 150 amperes. 44 Hz or 76 Hz, modulated and unmodulated.
14 May thru 6 Oct.	Began continuous 150 ampere Operation, 4pm - 8am EDT (16 hrs/day, on weekdays and all-day on weekends. Both antennas at 150 amperes. 76 Hz, modulated and unmodulated.
	Intermittent operation 8am - 4pm EDT weekdays. One or both antennas at 150 amperes. 44 Hz or 76 Hz, modulated and unmodulated.
7 Oct. to present	MTF is an on-line Navy communications facility. Continuous operation except for scheduled maintenance from 9am -2pm EDT on Tuesdays and Thursdays. Both antennas at 150 amperes, 76 Hz, modulated.

TABLE 3. 60 Hz TRANSVERSE ELECTRIC FIELD INTENSITIES (V/m)
Upland Flora and Soil Microflora Studies
(page 1 of 2)

Site No., Meas. Pt.	1983 [a]	1984 [a]	1985 [a]	1986 [b]	1987 [c]	1988 [c]	1989 [d]
4C1-6	-	0.003	<	<	<	<	<
4C1-7	-	0.006	<	<	<	<	<
4C1-8	-	0.004	<	<	<	<	<
4C1-9	-	0.002	<	<	<	<	<
4C1-10	-	-	<	<	<	<	<
4C1-11	-	-	<	<	<	<	<
4C1-12	-	-	<	<	<	<	<
4C1-13	-	-	<	<	<	<	<
4T2-3	-	0.001	<	<	<	0.002	#
4T2-4	-	-	<	<	<	0.001	#
4T2-5	-	-	<	<	<	0.011	#
4T2-6	-	-	<	<	<	<0.001	#
4T2-7	-	-	<	<	<	<0.001	#
4T2-8	-	-	<	<	<	/	#
4T2-9	-	-	<	<	<	<	#
4T2-10	-	-	<	<	<	<	#
4T2-11	-	-	<	<	<	<	#
4T2-12	-	-	<	<	<	/	#
4T2-13	-	-	<	<	<	<0.001	#
4T2-14	-	-	<	<	<	0.011	#
4T2-15	-	-	-	-	-	-	#
4T2-16	-	-	-	-	-	-	#
4T2-17	-	-	-	-	-	-	#
4T2-18	-	-	-	-	-	-	#
4T2-19	-	-	-	-	-	-	#

a = prior to antenna construction.
b = antennas grounded at transmitter.
c = antennas off, connected to transmitter.
d = both antennas on, 150 A current.

\- = measurement point not established.
/ = measurement not taken.
= measurement not possible.
< = estimated <0.001 V/m based on E in ground.

TABLE 3. 60 Hz TRANSVERSE ELECTRIC FIELD INTENSITIES (V/m)
Upland Flora and Soil Microflora Studies
(page 2 of 2)

Site No., Meas. Pt.	a 1983	a 1984	a 1985	b 1986	c 1987	c 1988	d 1989
4T4-4	-	0.003	<	<	<0.001	<0.001	#
4T4-5	-	-	<	<	0.006	0.003	#
4T4-6	-	-	<	<	<	<	#
4T4-7	-	-	<	<	<	<	#
4T4-8	-	-	<	<	<	<	#
4T4-9	-	-	<	<	<	<	#
4T4-10	-	-	<	<	<	<	#
4T4-11	-	-	<	<	0.010	0.009	#
4T4-12	-	-	-	<	0.005	0.007	#
4T4-13	-	-	-	-	-	-	#
4T4-14	-	-	-	-	-	-	#
4T4-15	-	-	-	-	-	-	#
4T4-16	-	-	-	-	-	-	#
4T4-17	-	-	-	-	-	-	#
4T4-18	-	-	-	-	-	-	#
4T4-19	-	-	-	-	-	-	#
4T4-20	-	-	-	-	-	-	#
4S1-1	-	-	-	-	0.013	0.033	0.011
4S2-1	-	-	-	-	<	<	<
4S3-1	-	-	-	-	<0.001	<0.001	<0.001

a = prior to antenna construction.
b = antennas grounded at transmitter.
c = antennas off, connected to transmitter.
d = both antennas on, 150 A current.

\- = measurement point not established.
/ = measurement not taken.
= measurement not possible.
< = estimated <0.001 V/m based on E in ground.

TABLE 4. 60 Hz LONGITUDINAL ELECTRIC FIELD INTENSITES (mV/m)
Upland Flora and Soil Microflora Studies
(page 1 of 2)

Site No., Meas. Pt.	a 1983	a 1984	a 1985	b 1986	c 1987	c 1988	d 1989
4C1-6	-	0.022	0.016	0.005	0.043	0.023	0.016
4C1-7	-	0.143	0.123	0.077	0.178	0.118	0.030
4C1-8	-	0.104	0.117	0.077	0.131	0.078	0.018
4C1-9	-	0.011	0.019	0.024	0.034	0.032	0.023
4C1-10	-	-	0.090	0.068	0.118	0.106	0.054
4C1-11	-	-	0.160	0.107	0.132	0.146	0.066
4C1-12	-	-	0.104	0.101	0.075	0.093	0.042
4C1-13	-	-	0.040	0.030	0.046	0.065	0.025
4T2-3	-	0.51	0.39	0.194	0.27	0.28	#
4T2-4	-	-	0.27	0.24	0.30	0.25	#
4T2-5	-	-	0.43	0.32	0.20	0.20	#
4T2-6	-	-	0.66	0.46	0.192	0.22	#
4T2-7	-	-	0.42	0.52	0.197	0.28	#
4T2-8	-	-	0.47	0.190	0.22	/	#
4T2-9	-	-	0.49	0.31	0.183	0.25	#
4T2-10	-	-	0.44	0.32	0.155	0.166	#
4T2-11	-	-	0.51	0.40	0.31	0.43	#
4T2-12	-	-	0.47	0.38	0.24	/	#
4T2-13	-	-	0.76	0.31	0.31	0.25	#
4T2-14	-	-	0.61	0.29	0.35	0.21	#
4T2-15	-	-	-	-	-	-	#
4T2-16	-	-	-	-	-	-	#
4T2-17	-	-	-	-	-	-	#
4T2-18	-	-	-	-	-	-	#
4T2-19	-	-	-	-	-	-	#

a = prior to antenna construction.
b = antennas grounded at transmitter.
c = antennas off, connected to transmitter.
d = both antennas on, 150 A current.

\- = measurement point not established.
/ = measurement not taken.
\# = measurement not possible.

TABLE 4. 60 Hz LONGITUDINAL ELECTRIC FIELD INTENSITES (mV/m)
Upland Flora and Soil Microflora Studies
(page 2 of 2)

Site No., Meas. Pt.	a 1983	a 1984	a 1985	b 1986	c 1987	c 1988	d 1989
4T4-4	-	0.72	0.42	0.185	0.56	0.079	#
4T4-5	-	-	0.58	0.58	4.3	1.12	#
4T4-6	-	-	0.22	0.16	0.61	0.188	#
4T4-7	-	-	0.44	0.29	0.64	0.22	#
4T4-8	-	-	0.42	0.193	0.40	0.23	#
4T4-9	-	-	0.50	0.21	0.27	0.073	#
4T4-10	-	-	0.42	0.22	0.29	0.063	#
4T4-11	-	-	0.40	0.60	2.7	1.27	#
4T4-12	-	-	-	0.75	3.4	1.35	#
4T4-13	-	-	-	-	-	-	#
4T4-14	-	-	-	-	-	-	#
4T4-15	-	-	-	-	-	-	#
4T4-16	-	-	-	-	-	-	#
4T4-17	-	-	-	-	-	-	#
4T4-18	-	-	-	-	-	-	#
4T4-19	-	-	-	-	-	-	#
4T4-20	-	-	-	-	-	-	#
4S1-1	-	-	-	-	8.5	12.2	11.6
4S2-1	-	-	-	-	0.155	0.109	0.032
4S3-1	-	-	-	-	0.65	1.73	0.73

a = prior to antenna construction.
b = antennas grounded at transmitter.
c = antennas off, connected to transmitter.
d = both antennas on, 150 A current.

\- = measurement point not established.
/ = measurement not taken.
= measurement not possible.

TABLE 5. 60 Hz MAGNETIC FLUX DENSITIES (mG)
Upland Flora and Soil Microflora Studies
(page 1 of 2)

Site No., Meas. Pt.	1983 [a]	1984 [a]	1985 [a]	1986 [b]	1987 [c]	1988 [c]	1989 [d]
4C1-6	-	0.003	0.003	0.003	0.002	0.003	0.002
4C1-7	-	0.003	0.002	0.001	0.003	0.002	0.001
4C1-8	-	0.003	0.003	0.002	0.003	0.002	0.001
4C1-9	-	0.003	0.003	0.002	0.001	0.002	0.002
4C1-10	-	-	0.002	0.002	0.002	0.002	0.002
4C1-11	-	-	0.002	0.002	0.002	0.002	0.001
4C1-12	-	-	0.002	0.003	0.001	0.002	0.001
4C1-13	-	-	0.002	0.003	0.001	0.003	0.002
4T2-3	-	0.002	0.001	0.001	0.003	0.005	#
4T2-4	-	-	0.001	0.001	0.003	0.006	#
4T2-5	-	-	0.001	0.007	0.017	0.030	#
4T2-6	-	-	0.001	0.006	0.006	0.014	#
4T2-7	-	-	0.001	0.004	0.004	0.007	#
4T2-8	-	-	0.001	0.002	0.004	/	#
4T2-9	-	-	0.001	0.003	0.003	0.005	#
4T2-10	-	-	0.001	0.003	0.003	0.005	#
4T2-11	-	-	0.001	0.004	0.005	0.007	#
4T2-12	-	-	0.002	0.004	0.005	/	#
4T2-13	-	-	0.001	0.005	0.008	0.013	#
4T2-14	-	-	0.002	0.011	0.018	0.029	#
4T2-15	-	-	-	-	-	-	#
4T2-16	-	-	-	-	-	-	#
4T2-17	-	-	-	-	-	-	#
4T2-18	-	-	-	-	-	-	#
4T2-19	-	-	-	-	-	-	#

a = prior to antenna construction.
b = antennas grounded at transmitter.
c = antennas off, connected to transmitter.
d = both antennas on, 150 A current.

\- = measurement point not established.
/ = measurement not taken.
\# = measurement not possible.

TABLE 5. 60 Hz MAGNETIC FLUX DENSITIES (mG)
Upland Flora and Soil Microflora Studies
(page 2 of 2)

Site No., Meas. Pt.	a 1983	a 1984	a 1985	b 1986	c 1987	c 1988	d 1989
4T4-4	-	0.004	0.002	0.001	0.003	0.003	#
4T4-5	-	-	0.002	0.006	0.010	0.017	#
4T4-6	-	-	0.002	0.001	0.004	0.007	#
4T4-7	-	-	0.001	0.001	0.004	0.005	#
4T4-8	-	-	0.002	0.001	0.004	0.005	#
4T4-9	-	-	0.002	0.001	0.002	0.003	#
4T4-10	-	-	0.001	0.001	0.002	0.002	#
4T4-11	-	-	0.002	0.002	0.012	0.019	#
4T4-12	-	-	-	0.002	0.010	0.016	#
4T4-13	-	-	-	-	-	-	#
4T4-14	-	-	-	-	-	-	#
4T4-15	-	-	-	-	-	-	#
4T4-16	-	-	-	-	-	-	#
4T4-17	-	-	-	-	-	-	#
4T4-18	-	-	-	-	-	-	#
4T4-19	-	-	-	-	-	-	#
4T4-20	-	-	-	-	-	-	#
4S1-1	-	-	-	-	0.035	0.043	0.052
4S2-1	-	-	-	-	0.003	0.002	0.002
4S3-1	-	-	-	-	0.036	0.095	0.028

a = prior to antenna construction.
b = antennas grounded at transmitter.
c = antennas off, connected to transmitter.
d = both antennas on, 150 A current.

\- = measurement point not established.
/ = measurement not taken.
= measurement not possible.

TABLE 6. 76 Hz TRANSVERSE ELECTRIC FIELD INTENSITIES (V/m)
Upland Flora and Soil Microflora Studies
(page 1 of 2)

SITE NO., MEAS.PT.	1986 NS 4 amp	1986 NEW 6 amp	1986 SEW 6 amp	1986 SEW 10 amp (EX)	1987 NS 15 amp	1987 EW 15 amp	1988 NS 75 amp	1988 EW 75 amp	1989 B 150 amp
4C1-6	<	<	<	*	<	<	<	<	<
4C1-7	<	<	<	*	<	<	<	<	<
4C1-8	<	<	<	*	<	<	<	<	<
4C1-9	<	<	<	*	<	<	<	<	<
4C1-10	<	<	<	*	<	<	<	<	<
4C1-11	<	<	<	*	<	<	<	<	<
4C1-12	<	<	<	*	<	<	<	<	<
4C1-13	<	<	<	*	<	<	<	<	<
4T2-3	<	<	0.004	0.007	0.002	0.014	0.006	0.125	0.142
4T2-4	<	<	0.005	0.008	0.001	0.014	0.017	0.113	0.149
4T2-5	0.018	<	0.092	0.153	0.003	0.23	0.033	2.6	1.31
4T2-6	<	<	0.005	0.008	0.003	0.013	0.014	0.142	0.138
4T2-7	<	<	0.007	0.012	0.001	0.018	0.020	0.165	0.173
4T2-8	<	<	0.004	0.007	0.002	0.012	/	/	0.124
4T2-9	<	<	0.005	0.008	0.002	0.010	0.019	0.137	0.12
4T2-10	<	<	0.004	0.007	0.002	0.011	0.020	0.112	0.113
4T2-11	<	<	0.003	0.005	0.002	0.012	0.010	0.130	0.22
4T2-12	<	<	0.002	0.003	0.002	0.014	/	/	0.095
4T2-13	<	<	0.005	0.008	0.002	0.012	0.010	0.121	0.125
4T2-14	0.030	<	0.155	0.26	0.003	0.186	0.026	2.5	1.66
4T2-15	-	-	-	-	-	-	-	-	2.3
4T2-16	-	-	-	-	-	-	-	-	1.92
4T2-17	-	-	-	-	-	-	-	-	0.69
4T2-18	-	-	-	-	-	-	-	-	0.28
4T2-19	-	-	-	-	-	-	-	-	0.107

NS = north-south antenna.
EW = east-west antenna.
NEW = northern EW antenna element.
SEW = southern EW antenna element.
B = NS + EW antennas, standard phasing.
EX = extrapolated data.

- = measurement point not established.
/ = measurement not taken.
= measurement not possible.
* = data cannot be extrapolated.
< = estimated <0.001 V/m based on E in ground.

TABLE 6. 76 Hz TRANSVERSE ELECTRIC FIELD INTENSITIES (V/m)
Upland Flora and Soil Microflora Studies
(page 2 of 2)

SITE NO., MEAS. PT.	1986 NS 4 amp	1986 NEW 6 amp	1986 SEW 6 amp	1986 SEW 10 amp (EX)	1987 NS 15 amp	1987 EW 15 amp	1988 NS 75 amp	1988 EW 75 amp	1989 B 150 amp
4T4-4	<	<	0.006	0.010	0.002	0.005	0.008	0.028	0.067
4T4-5	0.033	0.008	0.20	0.33	0.019	0.27	0.089	1.31	4.8
4T4-6	0.005	<	0.023	0.038	0.002	0.021	0.011	0.064	0.175
4T4-7	<	<	0.006	0.010	0.002	0.015	0.008	0.090	0.133
4T4-8	<	<	0.008	0.013	0.002	0.016	0.007	0.083	0.145
4T4-9	<	<	0.009	0.015	0.001	0.008	0.009	0.047	0.095
4T4-10	<	<	0.007	0.012	0.001	0.001	0.011	0.057	0.112
4T4-11	<	0.005	0.38	0.63	0.025	0.43	0.20	4.4	5.0
4T4-12	0.055	0.005	0.43	0.72	0.017	0.30	0.150	2.1	4.5
4T4-13	-	-	-	-	-	-	-	-	0.26
4T4-14	-	-	-	-	-	-	-	-	0.88
4T4-15	-	-	-	-	-	-	-	-	2.7
4T4-16	-	-	-	-	-	-	-	-	5.9
4T4-17	-	-	-	-	-	-	-	-	4.5
4T4-18	-	-	-	-	-	-	-	-	4.8
4T4-19	-	-	-	-	-	-	-	-	1.16
4T4-20	-	-	-	-	-	-	-	-	0.32
4S1-1	-	-	-	-	<	<	<	<	#
4S2-1	-	-	-	-	<	<	<	<	<
4S3-1	-	-	-	-	<	<	<	<	#

NS = north-south antenna.
EW = east-west antenna.
NEW = northern EW antenna element.
SEW = southern EW antenna element.
B = NS + EW antennas, standard phasing.
EX = extrapolated data.

- = measurement point not established.
/ = measurement not taken.
- measurement not possible.
* = data cannot be extrapolated.
< - estimated <0.001 V/m based on E in ground.

TABLE 7. 76 Hz LONGITUDINAL ELECTRIC FIELD INTENSITIES (mV/m)
Upland Flora and Soil Microflora Studies
(page 1 of 2)

SITE NO., MEAS. PT.	1986 NS 4 amp	1986 NEW 6 amp	1986 SEW 6 amp	1986 SEW 10 amp (EX)	1987 NS 15 amp	1987 EW 15 amp	1988 NS 75 amp	1988 EW 75 amp	1989 B 150 amp
4C1-6	<0.001	<0.001	<0.001	*	0.002	0.002	0.007	0.005	0.030
4C1-7	<0.001	<0.001	<0.001	*	0.005	0.006	0.024	0.023	0.091
4C1-8	<0.001	<0.001	<0.001	*	0.004	0.004	0.017	0.016	0.076
4C1-9	<0.001	<0.001	<0.001	*	0.002	0.002	0.007	0.006	0.030
4C1-10	<0.001	<0.001	<0.001	*	0.005	0.004	0.026	0.023	0.087
4C1-11	<0.001	<0.001	<0.001	*	0.006	0.005	0.028	0.028	0.113
4C1-12	<0.001	<0.001	<0.001	*	0.004	0.003	0.016	0.016	0.068
4C1-13	<0.001	<0.001	<0.001	*	0.002	0.002	0.012	0.011	0.051
4T2-3	1.31	0.22	6.3	10.5	1.36	15.2	7.7	76	131
4T2-4	1.05	0.22	5.0	8.3	1.70	10.7	6.2	68	135
4T2-5	1.18	0.24	5.3	8.8	1.46	12.7	8.2	62	86
4T2-6	1.11	0.27	4.4	7.3	2.2	12.4	10.4	56	105
4T2-7	1.13	0.23	5.3	8.8	1.31	9.7	8.8	71	90
4T2-8	1.32	0.25	5.7	9.5	1.81	15.8	/	/	141
4T2-9	1.17	0.21	5.1	8.5	1.46	13.7	7.1	63	119
4T2-10	0.97	0.22	4.1	6.8	1.84	10.5	8.1	50	96
4T2-11	1.14	0.21	5.0	8.3	2.2	10.7	9.6	122	182
4T2-12	1.06	0.21	4.3	7.2	1.93	13.5	/	/	99
4T2-13	1.12	0.64	5.4	9.0	1.74	14.9	8.2	71	138
4T2-14	1.07	0.175	5.1	8.5	1.66	14.3	6.6	56	124
4T2-15	-	-	-	-	-	-	-	-	73
4T2-16	-	-	-	-	-	-	-	-	88
4T2-17	-	-	-	-	-	-	-	-	104
4T2-18	-	-	-	-	-	-	-	-	95
4T2-19	-	-	-	-	-	-	-	-	107

NS = north-south antenna.
EW = east-west antenna.
NEW = northern EW antenna element.
SEW = southern EW antenna element.
B = NS + EW antennas, standard phasing.
EX = extrapolated data.

\- = measurement point not established.
/ = measurement not taken.
= measurement not possible.
* = data cannot be extrapolated.

TABLE 7. 76 Hz LONGITUDINAL ELECTRIC FIELD INTENSITIES (mV/m)
Upland Flora and Soil Microflora Studies
(page 2 of 2)

	1986				1987		1988		1989
SITE NO., MEAS.PT.	NS 4 amp	NEW 6 amp	SEW 6 amp	SEW 10 amp (EX)	NS 15 amp	EW 15 amp	NS 75 amp	EW 75 amp	B 150 amp
4T4-4	0.33	0.181	1.46	2.4	1.63	3.7	7.2	16.5	42
4T4-5	13.8	2.0	81.	135.	14.0	194.	68	910	2100
4T4-6	1.22	0.22	6.2	10.3	2.2	12.9	10.3	62	140
4T4-7	0.94	0.175	5.5	9.2	2.0	14.1	9.1	62	119
4T4-8	0.91	0.188	5.3	8.8	1.36	10.7	6.8	65	106
4T4-9	0.29	0.130	1.32	2.2	1.08	3.0	7.5	18.1	47
4T4-10	0.29	0.169	1.63	2.7	1.35	3.9	5.1	16.0	39
4T4-11	0.59	1.82	89.	148.	10.7	178.	50	850	1870
4T4-12	21.	2.2	118.	197.	13.8	260.	40	760	1950
4T4-13	-	-	-	-	-	-	-	-	64
4T4-14	-	-	-	-	-	-	-	-	220
4T4-15	-	-	-	-	-	-	-	-	760
4T4-16	-	-	-	-	-	-	-	-	3000
4T4-17	-	-	-	-	-	-	-	-	130
4T4-18	-	-	-	-	-	-	-	-	3200
4T4-19	-	-	-	-	-	-	-	-	750
4T4-20	-	-	-	-	-	-	-	-	200
4S1-1	-	-	-	-	<0.001	<0.001	<0.001	<0.001	#
4S2-1	-	-	-	-	0.005	0.005	0.026	0.026	0.126
4S3-1	-	-	-	-	<0.001	<0.001	<0.001	<0.001	#

NS = north-south antenna.
EW = east-west antenna.
NEW = northern EW antenna element.
SEW = southern EW antenna element.
B = NS + EW antennas, standard phasing.
EX = extrapolated data.

- = measurement point not established.
/ = measurement not taken.
= measurement not possible.
* = data cannot be extrapolated.

TABLE 8. 76 Hz MAGNETIC FLUX DENSITIES (mG)
Upland Flora and Soil Microflora Studies
(page 1 of 2)

SITE NO., MEAS. PT.	1986 NS 4 amp	1986 NEW 6 amp	1986 SEW 6 amp	1986 SEW 10 amp (EX)	1987 NS 15 amp	1987 EW 15 amp	1988 NS 75 amp	1988 EW 75 amp	1989 B 150 amp
4C1-6	<0.001	<0.001	<0.001	*	<0.001	<0.001	0.001	0.001	0.003
4C1-7	<0.001	<0.001	<0.001	*	<0.001	<0.001	0.001	<0.001	0.002
4C1-8	<0.001	<0.001	<0.001	*	<0.001	<0.001	0.001	<0.001	0.002
4C1-9	<0.001	<0.001	<0.001	*	<0.001	<0.001	0.001	0.001	0.003
4C1-10	<0.001	<0.001	<0.001	*	<0.001	<0.001	0.001	<0.001	0.002
4C1-11	<0.001	<0.001	<0.001	*	<0.001	<0.001	0.001	<0.001	0.002
4C1-12	<0.001	<0.001	<0.001	*	<0.001	<0.001	0.001	<0.001	0.002
4C1-13	<0.001	<0.001	<0.001	*	<0.001	<0.001	0.001	0.001	0.003
4T2-3	0.047	0.001	0.22	0.37	0.008	0.55	0.040	2.8	5.7
4T2-4	0.049	0.001	0.24	0.40	0.008	0.57	0.041	2.9	5.8
4T2-5	0.197	<0.001	1.00	1.67	0.011	2.4	0.061	12.4	24
4T2-6	0.058	0.001	0.44	0.73	0.006	1.16	0.020	5.0	10.3
4T2-7	0.046	0.001	0.22	0.37	0.006	0.59	0.024	2.6	5.4
4T2-8	0.045	0.001	0.22	0.37	0.006	0.59	/	/	5.6
4T2-9	0.029	0.001	0.138	0.23	0.007	0.38	0.027	1.72	3.4
4T2-10	0.033	0.001	0.149	0.25	0.006	0.39	0.027	1.78	3.5
4T2-11	0.043	0.001	0.21	0.35	0.006	0.56	0.025	2.6	5.0
4T2-12	0.047	0.001	0.23	0.38	0.006	0.61	/	/	5.6
4T2-13	0.086	<0.001	0.43	0.72	0.005	1.14	0.020	5.1	10.1
4T2-14	0.21	<0.001	1.03	1.72	0.012	2.5	0.061	11.9	25
4T2-15	-	-	-	-	-	-	-	-	33
4T2-16	-	-	-	-	-	-	-	-	28
4T2-17	-	-	-	-	-	-	-	-	13.6
4T2-18	-	-	-	-	-	-	-	-	8.6
4T2-19	-	-	-	-	-	-	-	-	5.9

NS = north-south antenna.
EW = east-west antenna.
NEW = northern EW antenna element.
SEW = southern EW antenna element.
B = NS + EW antennas, standard phasing.
EX = extrapolated data.

\- = measurement point not established.
/ = measurement not taken.
= measurement not possible.
* = data cannot be extrapolated.

TABLE 8. 76 Hz MAGNETIC FLUX DENSITIES (mG)
Upland Flora and Soil Microflora Studies
(page 2 of 2)

SITE NO., MEAS.PT.	1986 NS 4 amp	1986 NEW 6 amp	1986 SEW 6 amp	1986 SEW 10 amp (EX)	1987 NS 15 amp	1987 EW 15 amp	1988 NS 75 amp	1988 EW 75 amp	1989 B 150 amp
4T4-4	0.019	<0.001	0.096	0.160	0.005	0.24	0.027	1.15	2.5
4T4-5	0.114	0.001	0.57	0.95	0.008	1.40	0.033	6.9	13.9
4T4-6	0.045	0.001	0.22	0.37	0.008	0.53	0.034	2.7	5.3
4T4-7	0.038	0.001	0.186	0.31	0.008	0.45	0.033	2.3	4.4
4T4-8	0.035	0.001	0.179	0.30	0.007	0.43	0.033	2.1	4.2
4T4-9	0.025	0.21	0.118	0.197	0.005	0.29	0.027	1.41	2.8
4T4-10	0.022	<0.001	0.116	0.193	0.005	0.27	0.027	1.33	2.7
4T4-11	0.161	0.001	0.80	1.33	0.011	1.89	0.042	8.9	18.7
4T4-12	0.115	0.001	0.58	0.97	0.010	1.37	0.041	7.1	14.5
4T4-13	-	-	-	-	-	-	-	-	2.7
4T4-14	-	-	-	-	-	-	-	-	7.0
4T4-15	-	-	-	-	-	-	-	-	11.9
4T4-16	-	-	-	-	-	-	-	-	18
4T4-17	-	-	-	-	-	-	-	-	14.3
4T4-18	-	-	-	-	-	-	-	-	16.8
4T4-19	-	-	-	-	-	-	-	-	9.8
4T4-20	-	-	-	-	-	-	-	-	5.9
4S1-1	-	-	-	-	<0.001	<0.001	<0.001	<0.001	#
4S2-1	-	-	-	-	<0.001	<0.001	0.001	<0.001	0.002
4S3-1	-	-	-	-	<0.001	<0.001	<0.001	<0.001	#

NS = north-south antenna.
EW = east-west antenna.
NEW = northern EW antenna element.
SEW = southern EW antenna element.
B = NS + EW antennas, standard phasing.
EX = extrapolated data.

\- = measurement point not established.
/ = measurement not taken.
= measurement not possible.
* = data cannot be extrapolated.

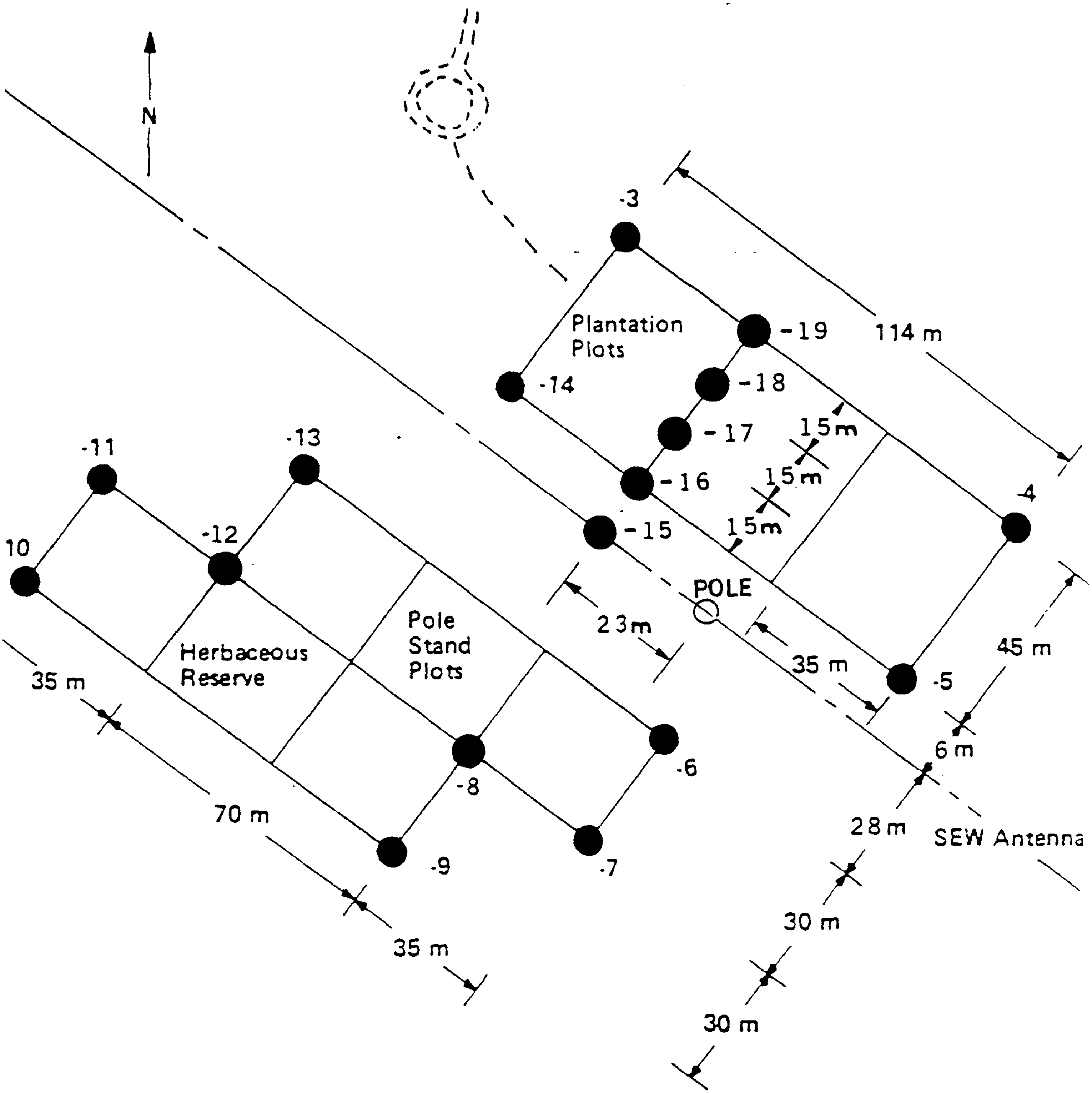


FIGURE 1. MARTELL'S LAKE (OVERHEAD): ML; 4T2-3 THRU -19

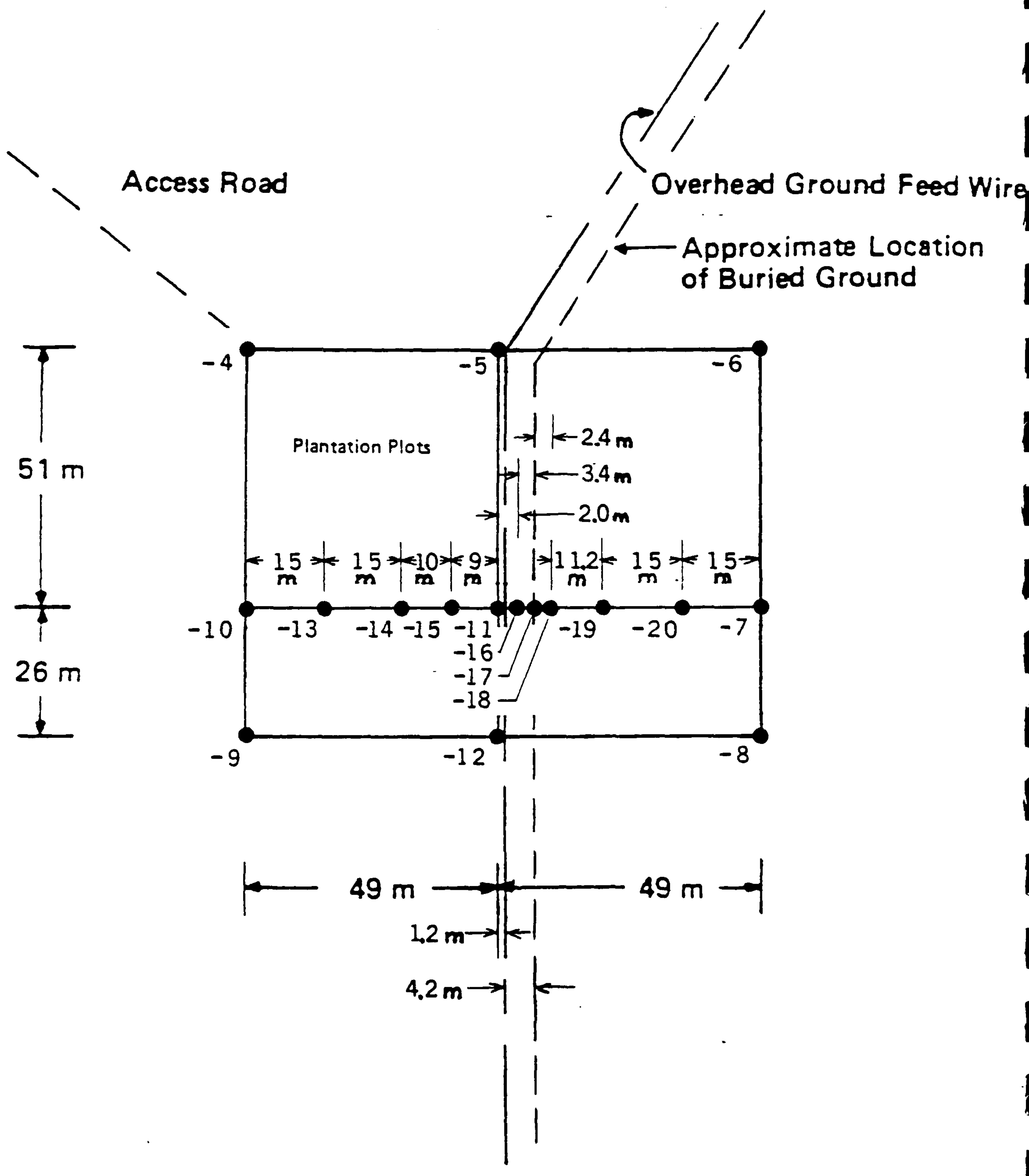


FIGURE 2. MARTELL'S LAKE (BURIED): EP; 4T4-4 THROUGH 12.

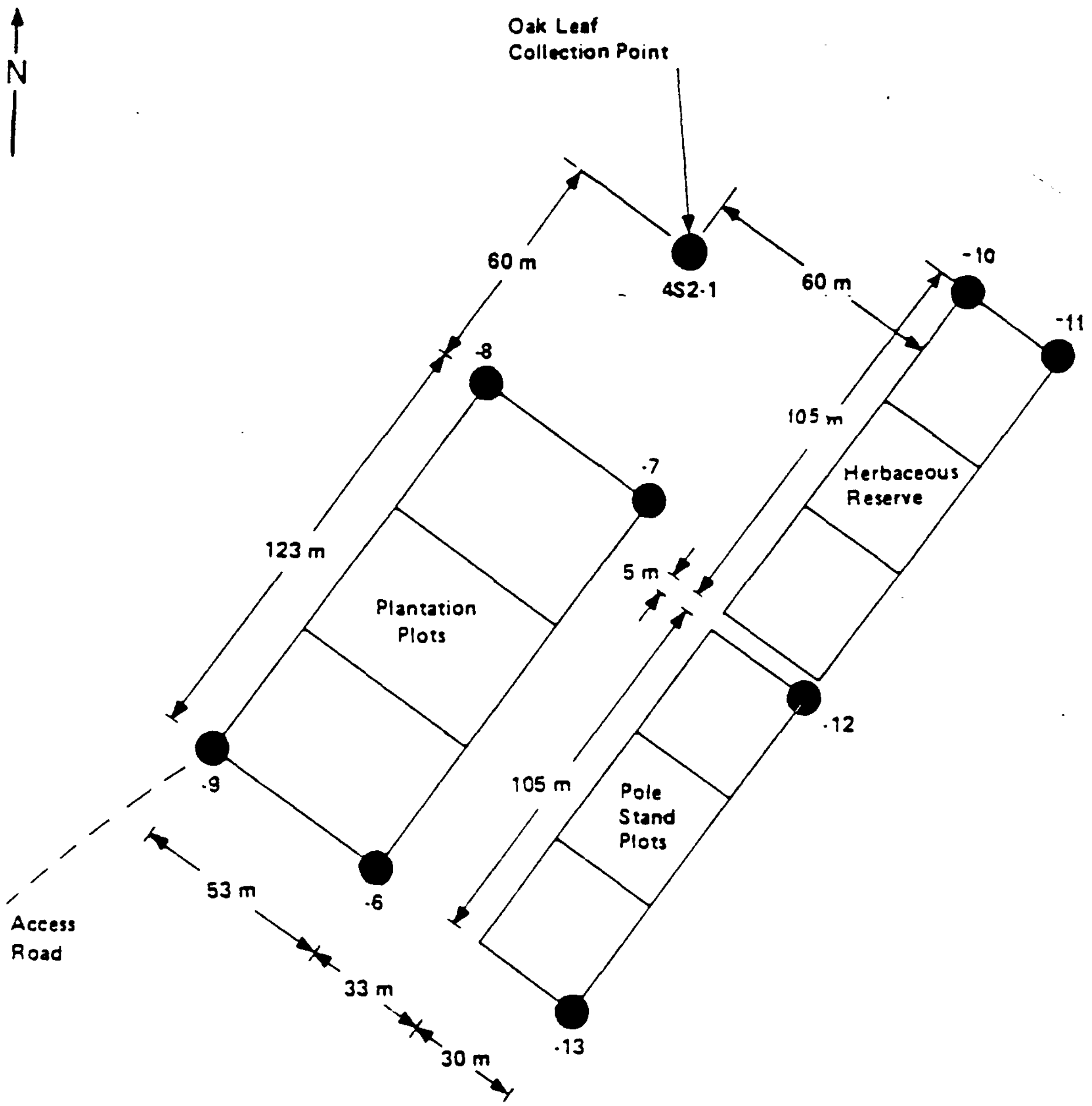


FIGURE 3. MEASUREMENT POINTS AT PAINT POND ROAD CONTROL; 4C1-6 THROUGH 13, AND OAK LEAF COLLECTION SITE; 4S2-1.

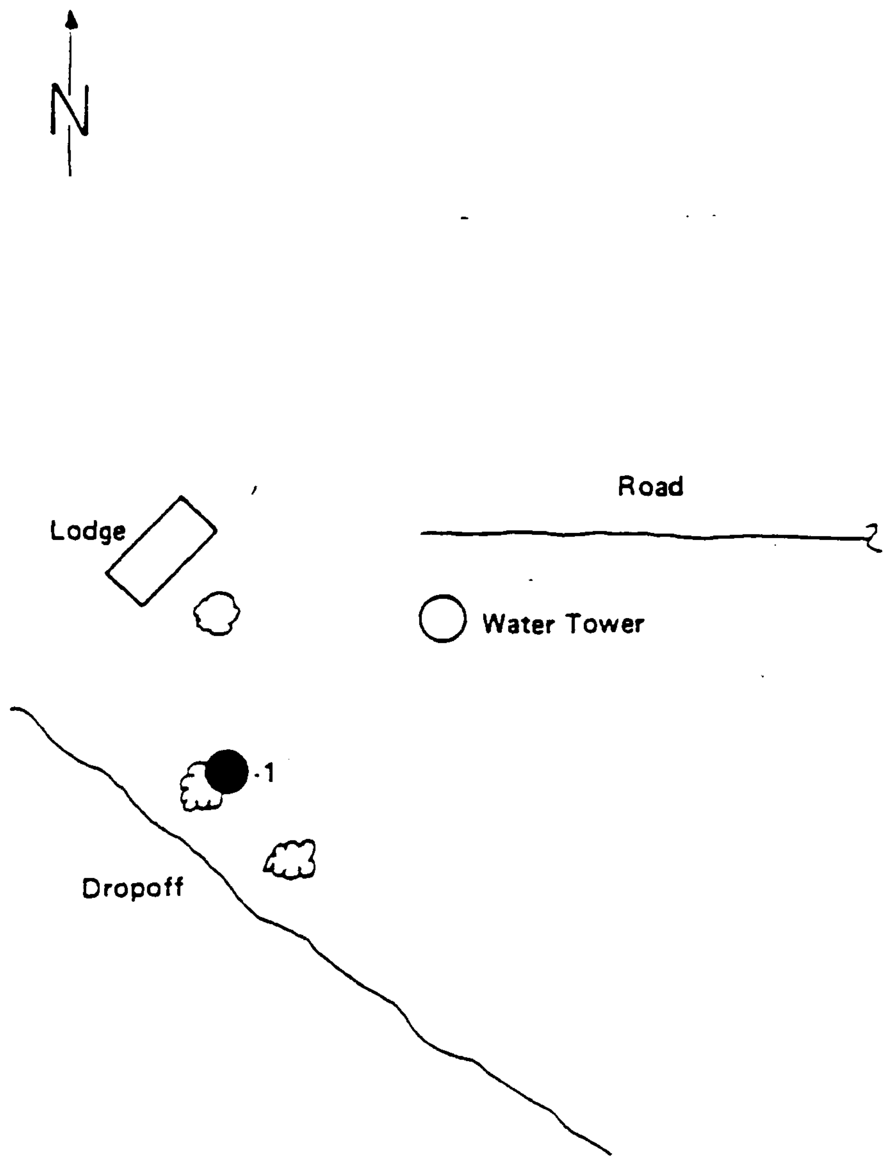


FIGURE 4. MEASUREMENT POINT AT RED MAPLE LEAF SAMPLE COLLECTION SITE; 4S1-1.

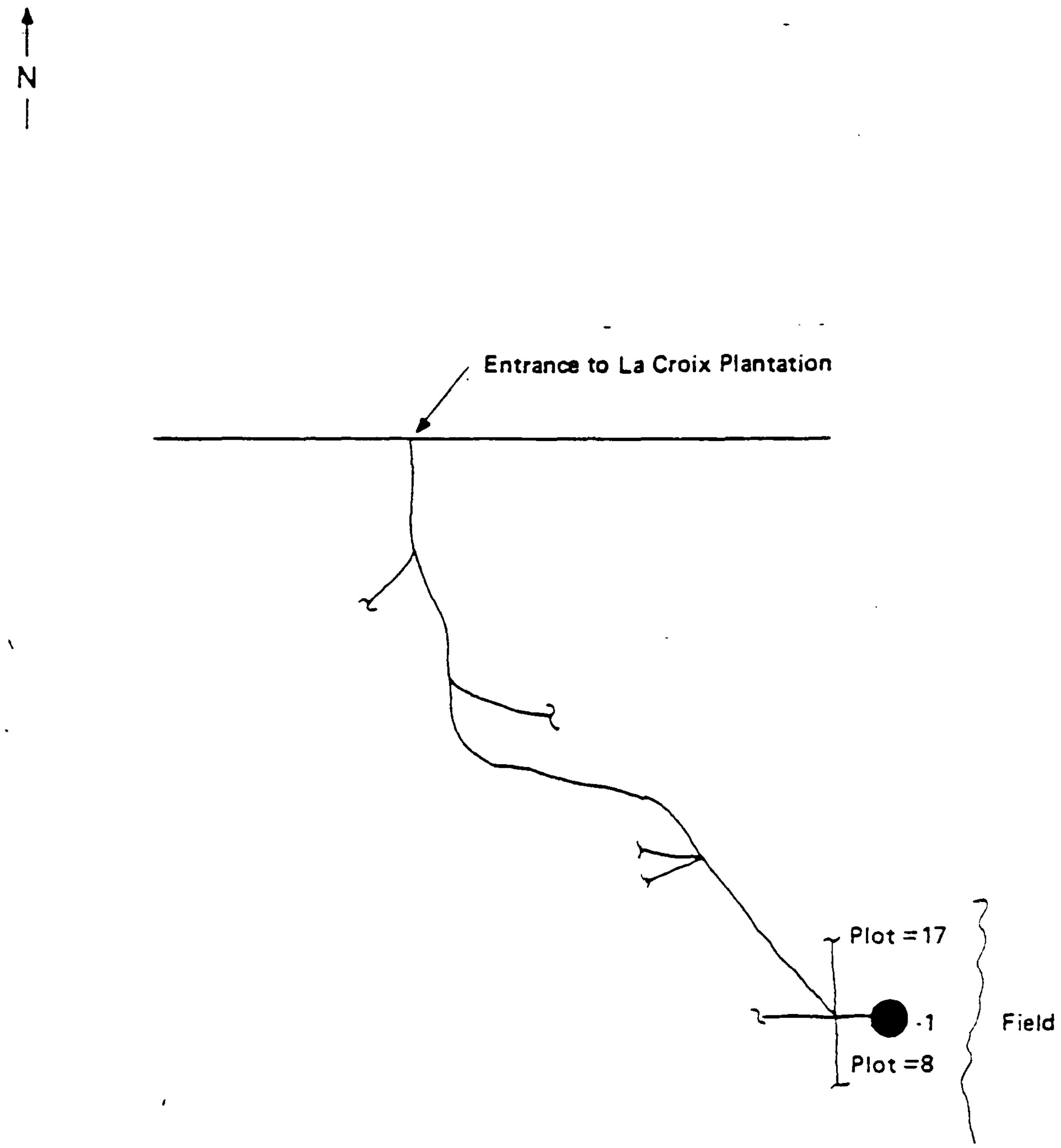


FIGURE 5. MEASUREMENT POINT AT THE PINE NEEDLE SAMPLE COLLECTION SITE; 4S3-1.

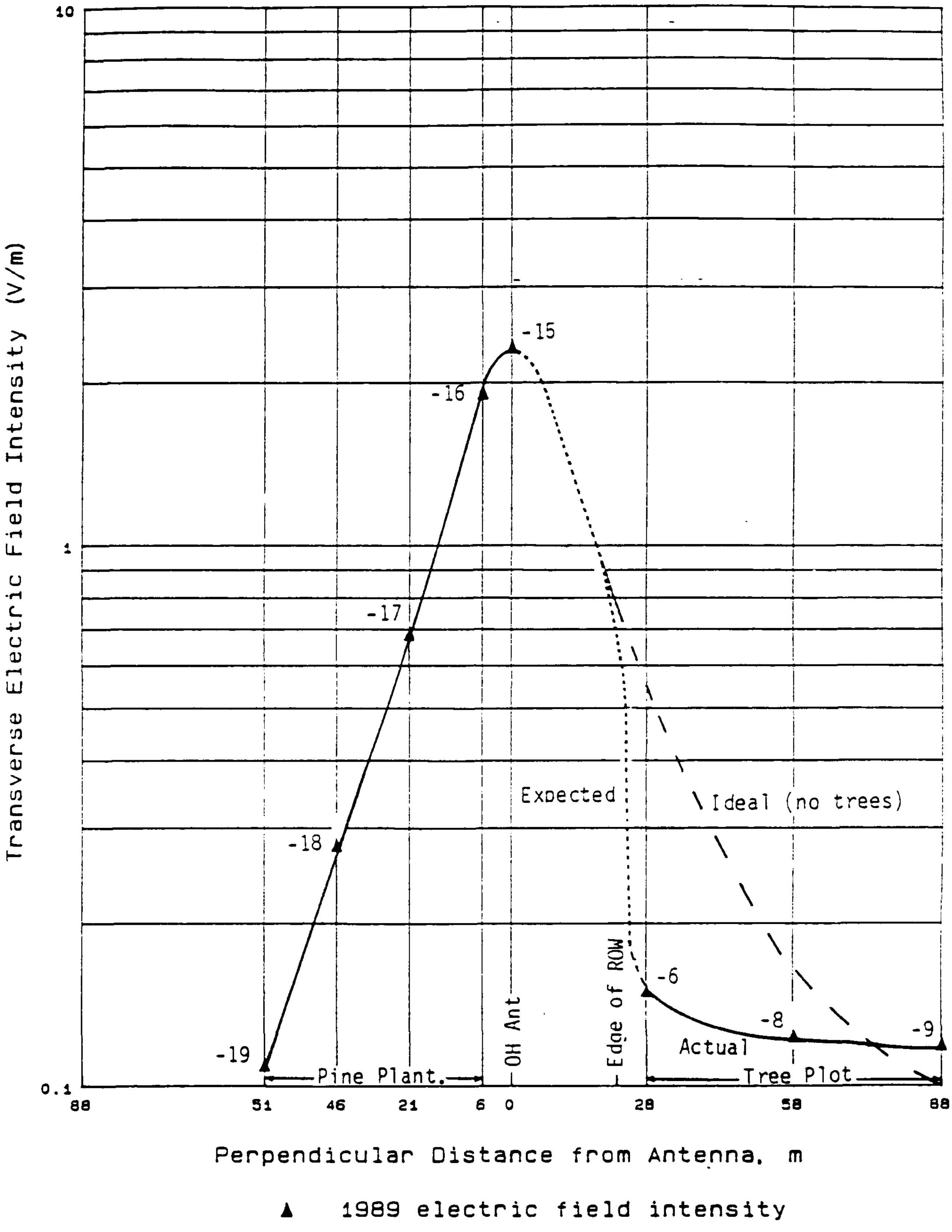


FIGURE 6. 76 Hz TRANSVERSE ELECTRIC FIELD PROFILES, MARTELL'S LAKE (OVERHEAD): ML: 4T2-8, 9, 15-19.

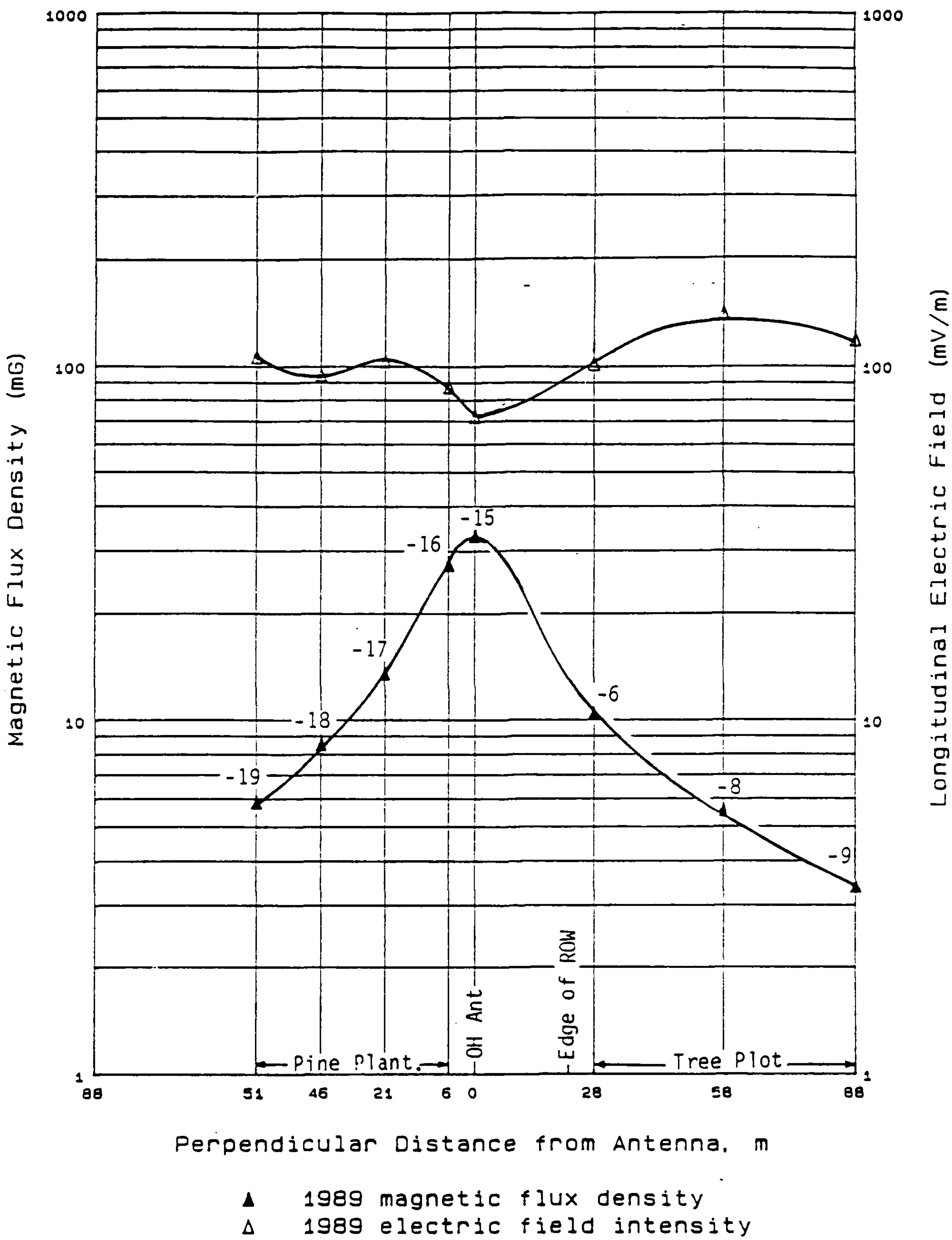


FIGURE 7. 76 Hz MAGNETIC & LONGITUDINAL ELECTRIC FIELD PROFILES, MARTELL'S LAKE (OVERHEAD): ML; 4T2-8, 9, 15-19.

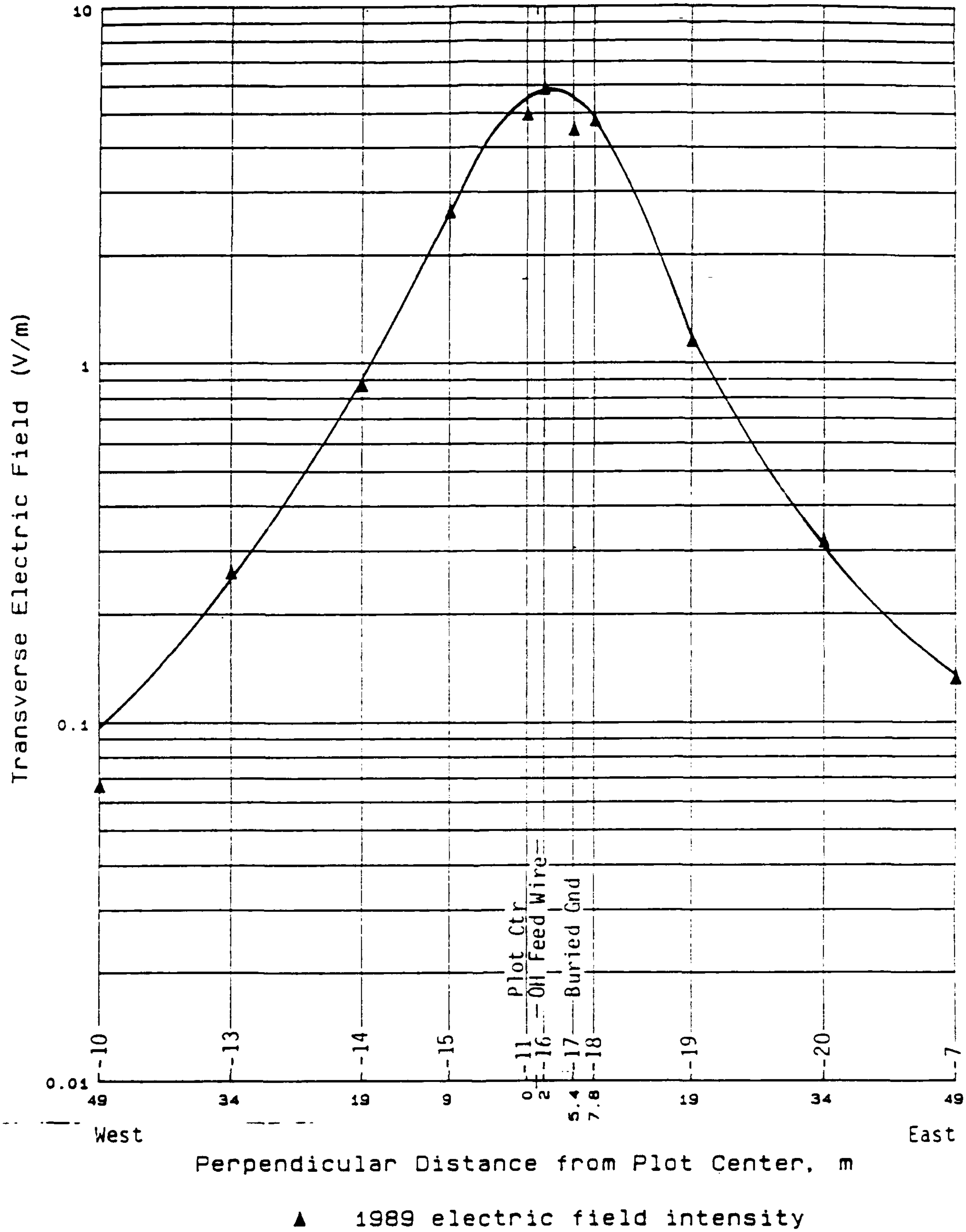


FIGURE 8. TRANSVERSE ELECTRIC FIELD PROFILE,
MARTELL'S LAKE (BURIED): EP: 4T4-7, 10, 11, 13-20.

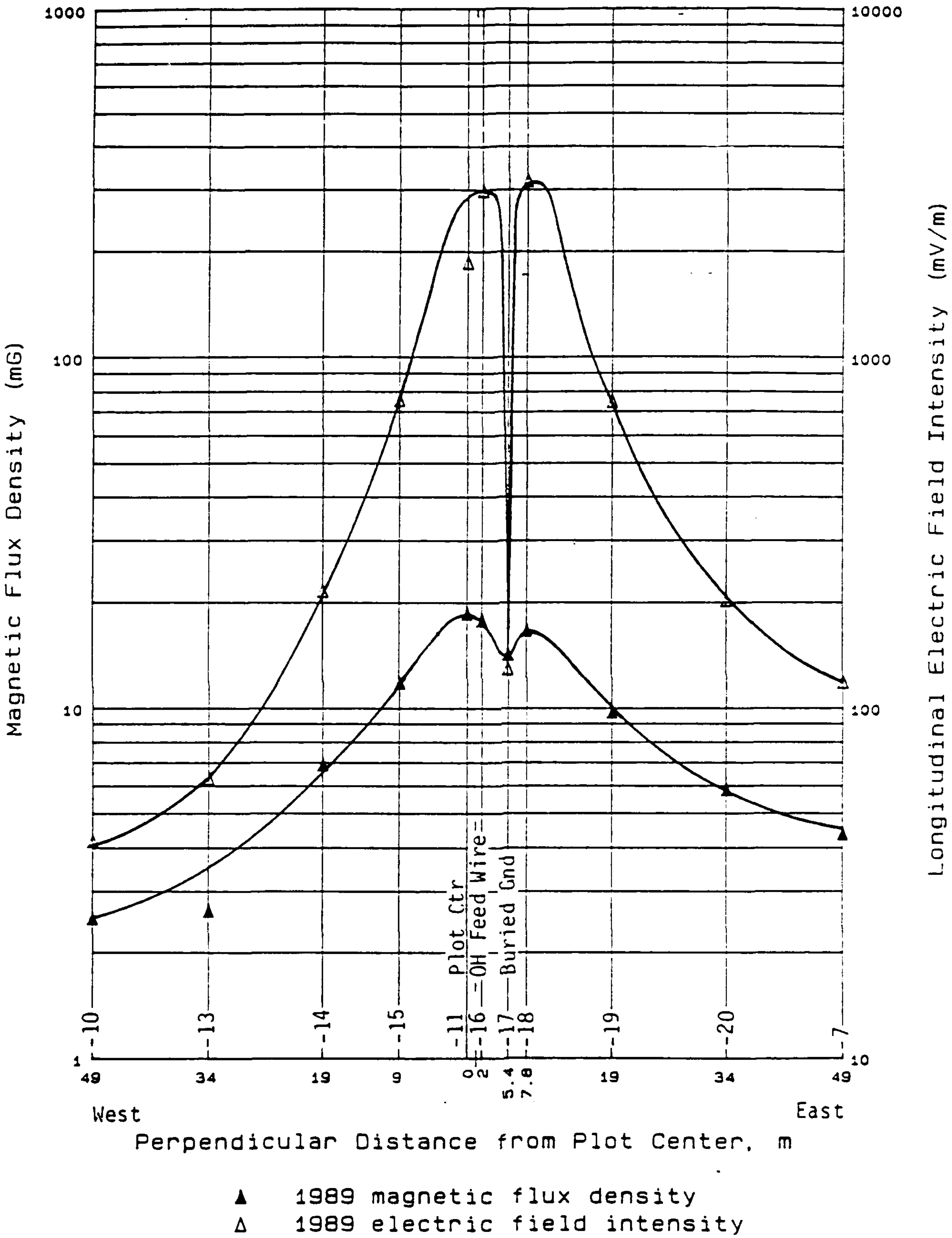


FIGURE 9. 76 Hz MAGNETIC & LONGITUDINAL ELECTRIC FIELD PROFILES, MARTELL'S LAKE (BURIED): EP: 4T4-7, 10, 11, 13-20.

To: Glenn

Date: November 7, 1989

From: Dave Reed

cc: Hal
Johann
Marty
Peg
Pete
Beth

Subject: ELF Field Exposure Data

In reviewing the equations I gave you for calculating ELF exposure rates on the sites, there was a mistake in the 76 Hz transverse field equations for the Antenna site. The following equations are correct:

$$1986\ \text{NS}\ \ V/m = 0.00293 + 0.0003637\,X$$

$$\text{EW}\ \ V/m = -0.04202 + 2.36301/X$$

$$1987\ \text{NS}\ \ V/m = 0.00293 - 0.0000161\,X$$

$$\text{EW}\ \ V/m = -0.04202 + 3.35815/X$$

$$1988\ \text{NS}\ \ V/m = -0.02007 + 0.0003637\,X + 0.55872/X$$

$$\text{EW}\ \ V/m = -2.78081 + 73.18741/X + 0.02512\,X$$

$$\text{NS}\quad R^2 = 0.956\qquad MSE = 1\times10^{-5}$$

$$\text{EW}\quad R^2 = 0.983\qquad MSE = 0.0138$$

I am currently reviewing the other equations and will let you know if there are any other problems.

To: Glenn

From: Dave Reed

Date: July 26, 1989

CC: Hal
Johann
Marty
Peg
Pete
Beth

Subject: ELF field exposure data

Attached is information on calculating ELF exposure information for any point in either the plantation or hardwood stands at any of our three study sites. This is based on IITRI's measurements made each summer. The exposure data consists of measurements made at two frequencies: 60 Hz and 76 Hz. The 60 Hz is background fields from the power grid, some of which is bleeding through the antenna lines leading to elevated 60 Hz fields at the antenna and ground sites in recent years. The antenna also operated at 44 Hz in 1988 but I don't know exactly how to extrapolate this to our data.

At each frequency, electrical fields are measured in two ways: transverse (vertical field in the air generated by the antenna) and longitudinal (field in the earth measured as a difference in potential at the surface). Transverse fields are impacted by physical objects such as trees but there was really no noticeable difference at this time between the hardwood and plantation samples; this may be due to sample size in that relatively few measurement points are used (see attached maps for each site). The longitudinal fields are less uniform since they are impacted by soil moisture, rocks, tree roots, etc. The measurements are made once each year so, at this time, we cannot evaluate the changes in field strength associated with changes in soil moisture measured by our probes. Magnetic flux associated with the antenna is also measured.

The 76 Hz fields represent the major impact of the antenna but, as mentioned above, there is some increase in 60 Hz fields as well. The north-south leg (NS) of the antenna and the east-west legs (EW) operate independently. Since our plots are along the southern east-west leg, the greatest exposures occur when the EW legs are operating. In calculating exposure amounts or indices, the separate operations of NS and EW should probably be considered.

There does not seem to be a clear consensus in the

literature on methods of estimating exposures. There seems to be a feeling that there may be windows in frequencies and strengths where bioeffects are greater. There is also no clear indication on whether maximum, average, or cumulative exposures have the greatest potential for biological impacts. There are some indications that the number of on-off cycles of current may also play a part. There is, therefore, no clear measure of exposure that we can all use; each of us is on our own in terms of calculating gauss-hours or other exposure measures. I think it is very important for us to keep in touch and if anyone finds anything particularly useful they should let everyone else know as soon as possible. For the hardwood trees work, we will initially calculate a field strength for each tree location each year, gauss-hours and volt-hours of exposure, and some index involving field strength and the number of on-off cycles.

On the attached pages are maps of each site giving the coordinate system I used in developing the exposure equations, the exposure equations giving field strengths for each site each year by location within the site, and summaries of IITRI's hours of operation data and the number of antenna on-off cycles by month for 1986, 1987, and 1988. In all cases, if a negative value is predicted for a point by an equation use 0.001 which is the minimum detection limit in the measurements.

IITRI Data - 1986 Hours of Antenna Operation

Month		NS	EW	
	Amps	4	6	10
Jan				
Feb				
Mar				3.87
Apr				18.64
May				6.15
Jun			11.72	
Jul		24.43		
Aug		16.74		
Sep		10.71	5.26	
Oct		11.49	5.76	
Nov				
Dec				
Total		63.55	22.74	28.66

IITRI Data - 1987 Hours of Antenna Operation

Month		NS	EW
	Amps	15	15
Jan			
Feb			
Mar			
Apr			
May			
Jun		44.40	43.95
Jul		27.59	27.81
Aug		32.40	32.39
Sep		38.86	38.61
Oct		33.08	33.94
Nov		21.79	21.90
Dec			
Total		198.12	198.60

IITRI Data - 1988 Hours of Antenna Operation

Month		NS		EW	
	Amps	15	75	15	75
Jan		27.13		27.14	
Feb		26.36		30.95	
Mar		27.14		31.48	
Apr		34.14		34.34	
May		41.23		41.33	
Jun		43.27		43.13	
Jul		0.19	27.62 (1.27)		31.10 (1.06)
Aug			59.53		68.99
Sep			34.24 (26.16)		34.71 (26.38)
Oct			52.86 (2.61)		56.05 (2.52)
Nov			12.67 (31.20)		12.67 (31.29)
Dec			23.76 (15.68)		23.76 (15.58)
Total		199.46	210.68 (76.92)	208.59	227.28 (76.83)

IITRI Data - 1986 Number of Operating Cycles

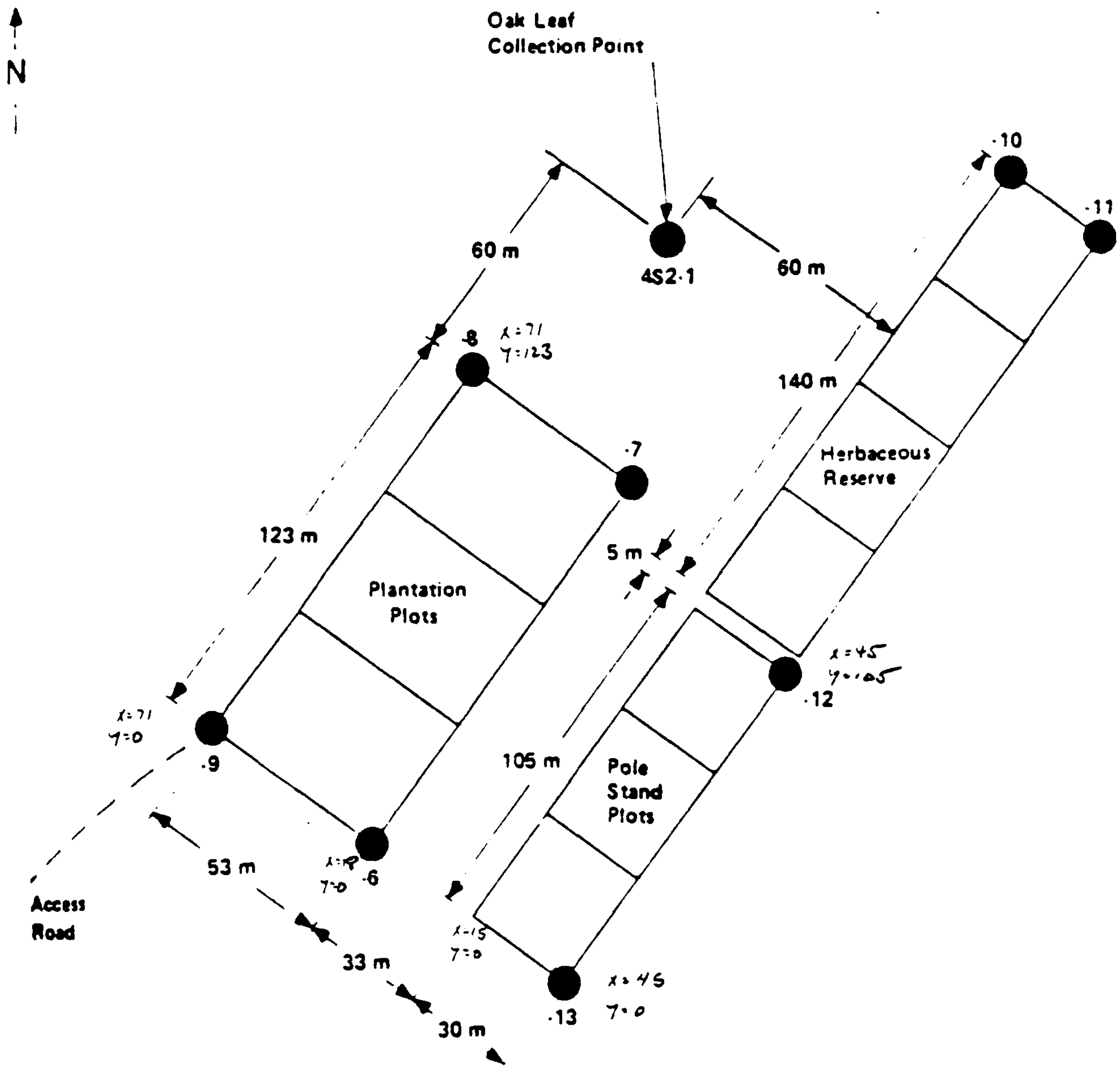
Month		NS		EW
	Amps	4	6	10
Jan				
Feb				
Mar				27
Apr				39
May				5
Jun			6	
Jul		145		
Aug		23		
Sep		31	30	
Oct		60	78	
Nov				
Dec				
Total		259	114	71

IITRI Data - 1987 Number of Operating Cycles

Month		NS	EW
	Amps	15	15
Jan			
Feb			
Mar			
Apr		1	1
May		1	1
Jun		533	527
Jul		331	334
Aug		389	389
Sep		466	463
Oct		397	407
Nov		262	263
Dec			
Total		2380	2385

IITRI Data - 1988 Number of Operating Cycles

Month		NS		EW	
	Amps	15	75	15	75
Jan		326		326	
Feb		316		371	
Mar		326		378	
Apr		410		412	
May		495		496	
Jun		519		518	
Jul			485		526
Aug			714		827
Sep			725		733
Oct			666		703
Nov			526		527
Dec			473		472
Total		2392	3589	2501	3788



D-2. MEASUREMENT POINTS AT PAINT POND ROAD CONTROL; 4C1-6 THROUGH 13, AND OAK LEAF COLLECTION SITE; 4S2-1.

Control Site Exposure Equations

60 Hz

Transverse (V/m)

No detectable in any year (< 0.001 V/m)

Longitudinal (mV/m)

mV/m = 0.04277 + 0.0003546 Y R^2=.58   MSE=0.030

Magnetic Flux (mG)

0.002

76 Hz

Transverse (V/m)

No detectable in any year (< 0.001)

Longitudinal (mV/m)

1986 No detectable (< 0.001)

1987 mV/m = 0.00229 + 0.00001246 Y R^2=.94 MSE=0.002

1988 mV/m = 0.00865 + 0.00007432 Y

Magnetic Flux (mG)

No detectable in any year (< 0.001)

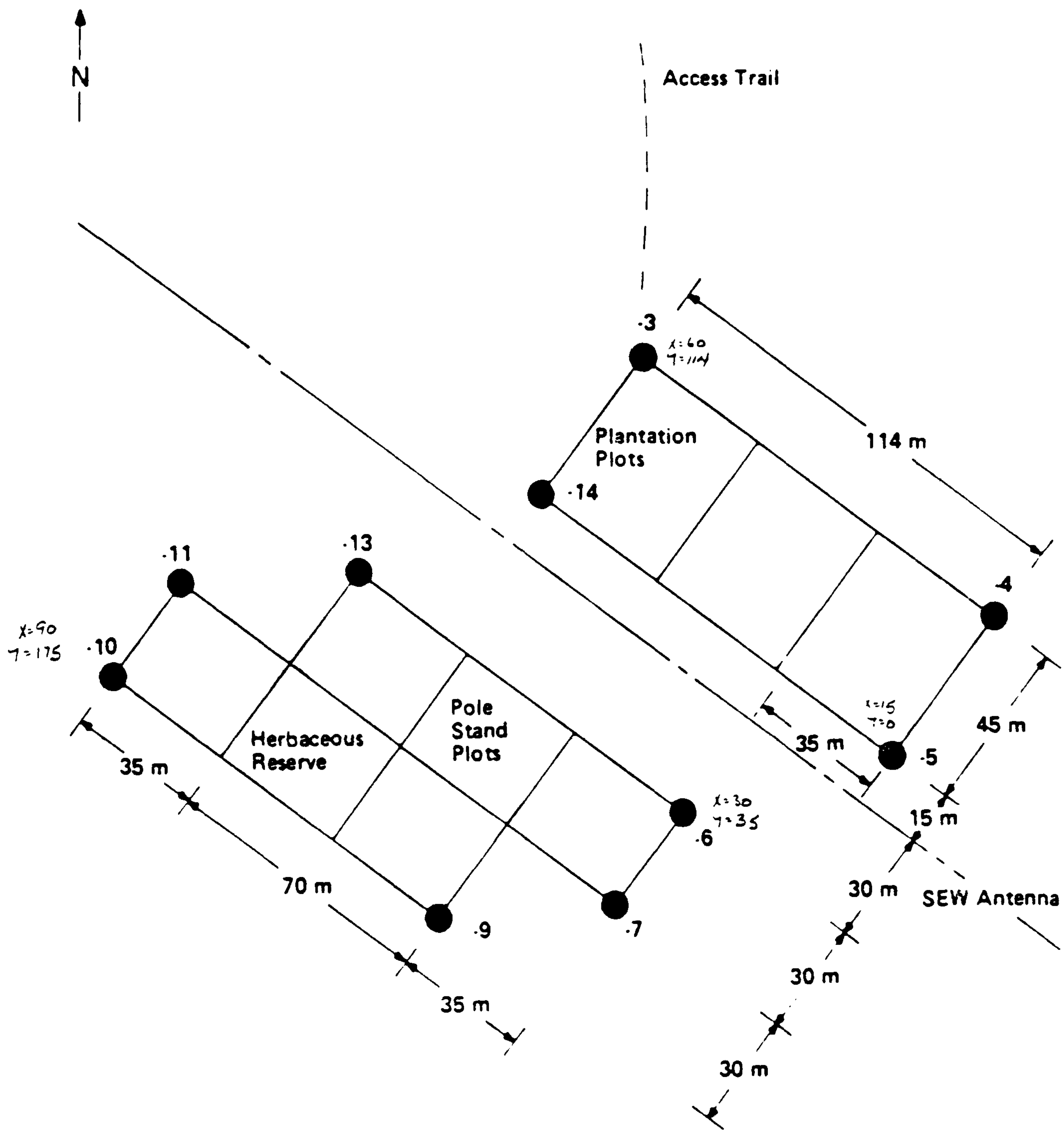


FIGURE D-3. MARTELL'S LAKE (OVERHEAD): ML; 4T2-3, 4, 5, 6, 7, 9, 10, 11, 13, 14.

60297/189

Antenna Site Exposure Equations

60 Hz

Transverse (V/m)

No detectable in 1985, 1986, or 1987 (< 0.001)

1988 $mV/m = 0.165/X$

Longitudinal (mV/m)

1985 $mV/m = 0.5198 - 0.001218X + 1.25054/X$ R^2=.62

1986 $mV/m = 0.5198 - 0.002272X - 2.6742/X$ MSE=0.094

1987 $mV/m = 0.5198 - 0.003569X - 3.2169/X$

1988 $mV/m = 0.5198 - 0.002712X - 4.3915/X$

Magnetic Flux (mG)

1985 $mG = 0.000633 + 0.00000517Y$ R^2=.98

1986 $mG = 0.000633 + 0.00000517Y + 0.1203/X$ MSE=0.001

1987 $mG = -0.00103 + 0.00000517Y + 0.2662/X$

1988 $mG = -0.00153 + 0.00000517Y + 0.4565/X$

Antenna Site Exposure Equations

76 Hz

Transverse (V/m)

1985 No detectable readings for either NS or EW

1986 NS No detectable readings

EW V/m = -0.2059 + 67.4395/X - 0.01523X

1987 NS V/m = -0.0381 + 0.02988/X + 0.0000049X

EW V/m = -0.2059 + 5.6748/X + 0.00188X

1988 NS V/m = -0.02007 + 0.6577/X - 0.00866X

EW V/m = -2.5116 + 67.4395/X + 0.02251X

Longitudinal (mV/m)

1986 NS mV/m = 1.135

EW mV/m = 5.083

1987 NS mV/m = 1.723

EW mV/m = 12.841

1988 NS mV/m = 12.235 - 0.0473X - 59.9483/X

EW mV/m = 113.691 - 0.5987X - 825.905/X + 0.1189 Y

Magnetic Flux (mG)

1986 NS mG = 0.01346 + 2.7476/X

EW mG = -0.05612 + 15.7437/X

1987 NS mG = 0.01346 - 0.1247/X

EW mG = -0.05612 + 37.4525/X

1988 NS mG = 0.01346 + 0.6694/X

EW mG = -2.454 + 213.0168/X + 0.02218X

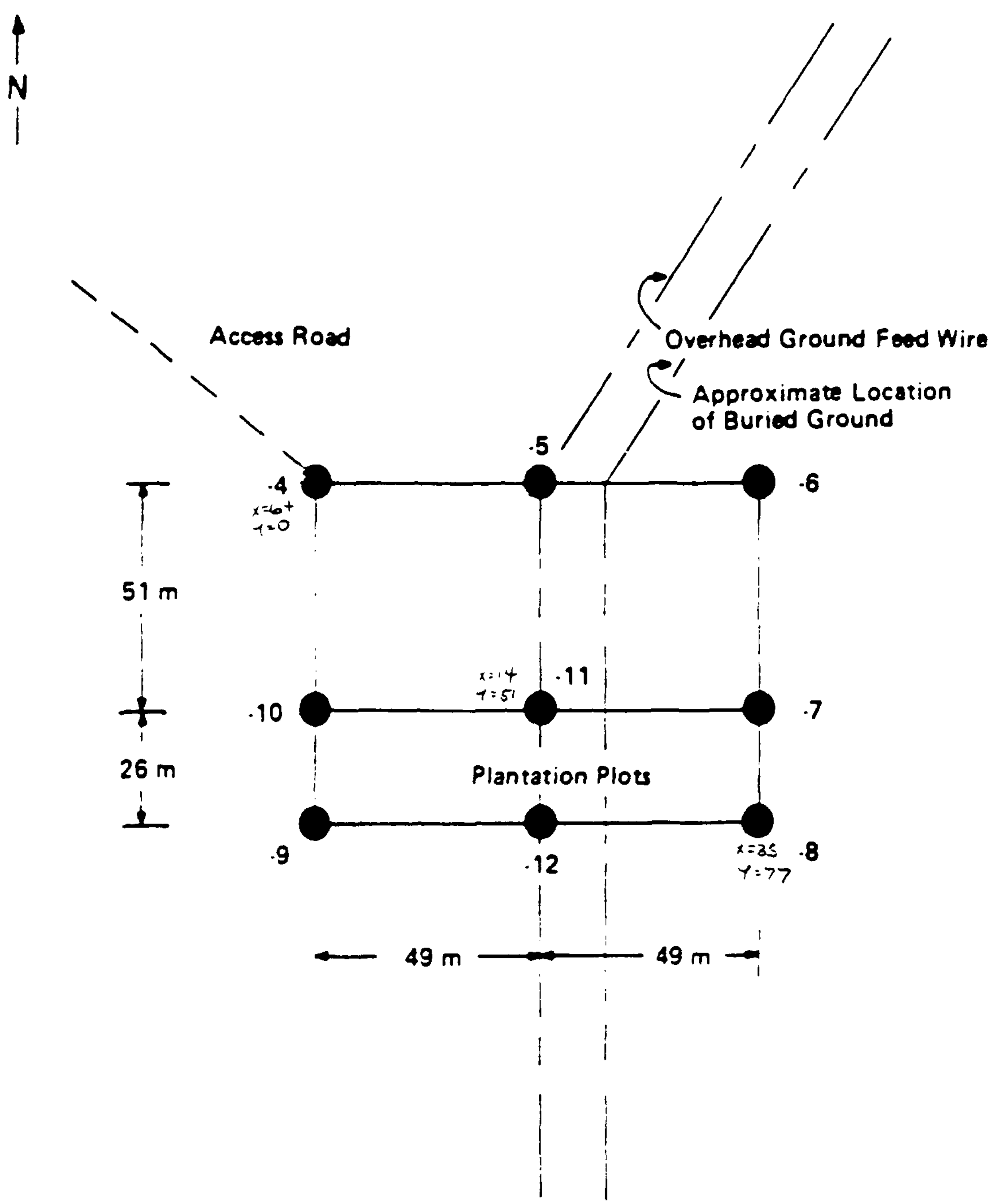


FIGURE D-4. MARTELL'S LAKE (BURIED): EP; 4T4-4 THROUGH 12.

Ground Site Exposure Equations

60 Hz

Transverse (V/m)

1985 and 1986 No detectable readings (< 0.001)

1987 and 1988 V/m = .00667/X

Longitudinal (mV/m)

1985 mV/m = 0.0201 + 8.6317/X

1986 mV/m = 0.0201 + 8.6317/X

1987 mV/m = -2.6241 + 83.2902/X + 0.0311X - 0.006887Y

1988 mV/m = 0.0201 + 15.240/X

Magnetic Flux (mG)

1985 mG = 0.000380 + 0.03505/X

1986 mG = 0.000380 + 0.03505/X

1987 mG = 0.000380 + 0.1410/X

1988 mG = 0.000380 + 0.2402/X - 0.0000275X

Ground Site Exposure Equations

76 Hz

Transverse (V/m)

1986 NS V/m = -0.0102 + 0.5527/X

EW V/m = -0.1238 + 6.2901/X

1987 NS V/m = -0.0102 + 0.5527/X

EW V/m = -0.1238 + 6.2901/X

1988 NS V/m = -0.1745 + 4.1261/X + 0.001865X

EW V/m = -0.9847 + 49.1286/X

Longitudinal (mV/m)

1986 NS mV/m = -20.541 + 0.2426X + 409.547/X

EW mV/m = -398.917 + 5.1353X + 6127.514/X

1987 NS mV/m = -20.541 + 0.2426X + 428.073/X

EW mV/m = -398.917 + 4.6125X + 7748.236/X

1988 NS mV/m = -20.541 + 0.2426X + 1051.696/X - 0.1458Y

EW mV/m = -398.917 + 1.8376X + 16661.306/X

Magnetic Flux (mG)

1986 NS mG = -0.0113 + 1.9565/X

EW mG = -0.1051 + 10.6914/X

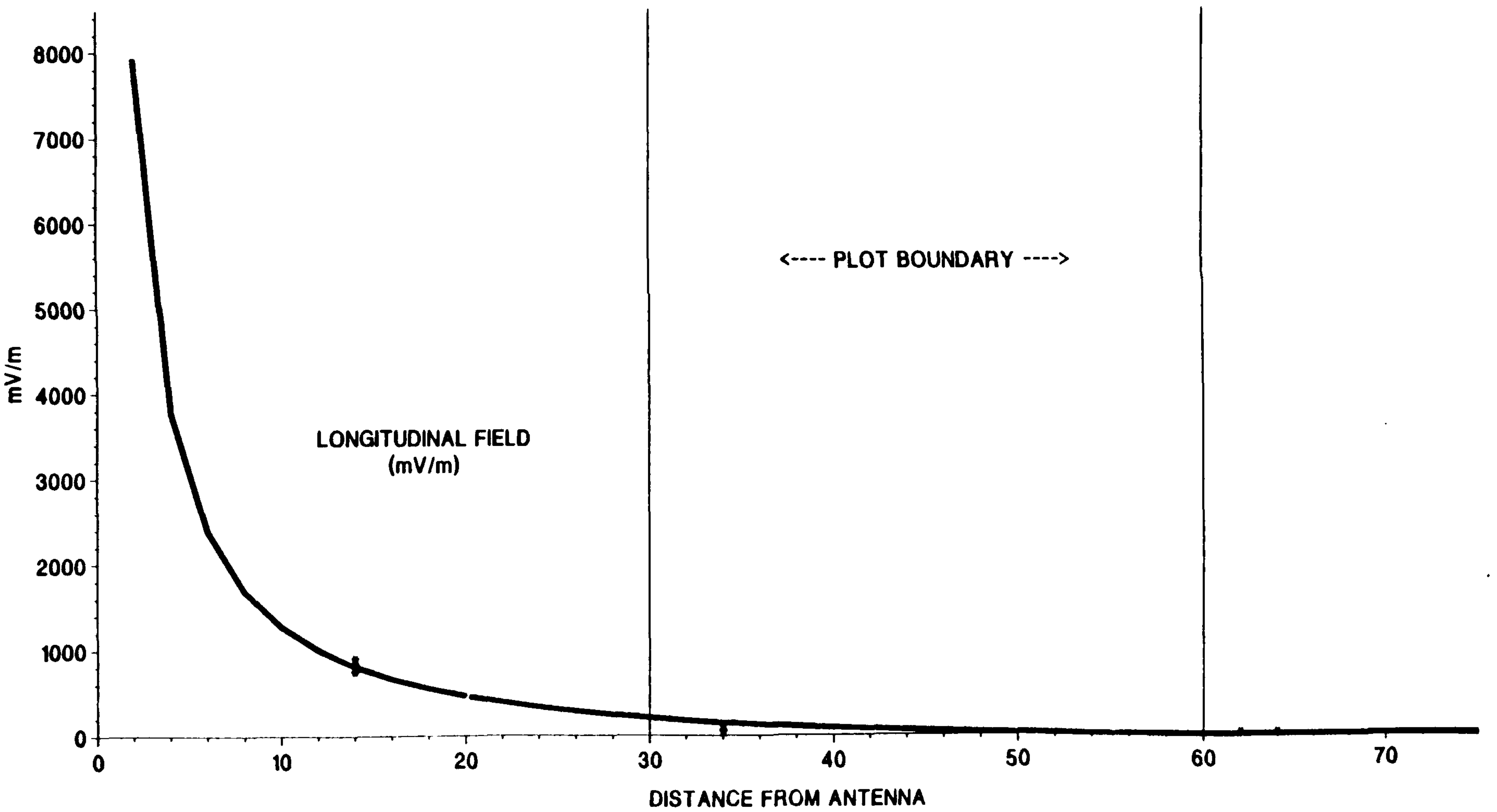
1987 NS mG = -0.0113 + 0.3718/X

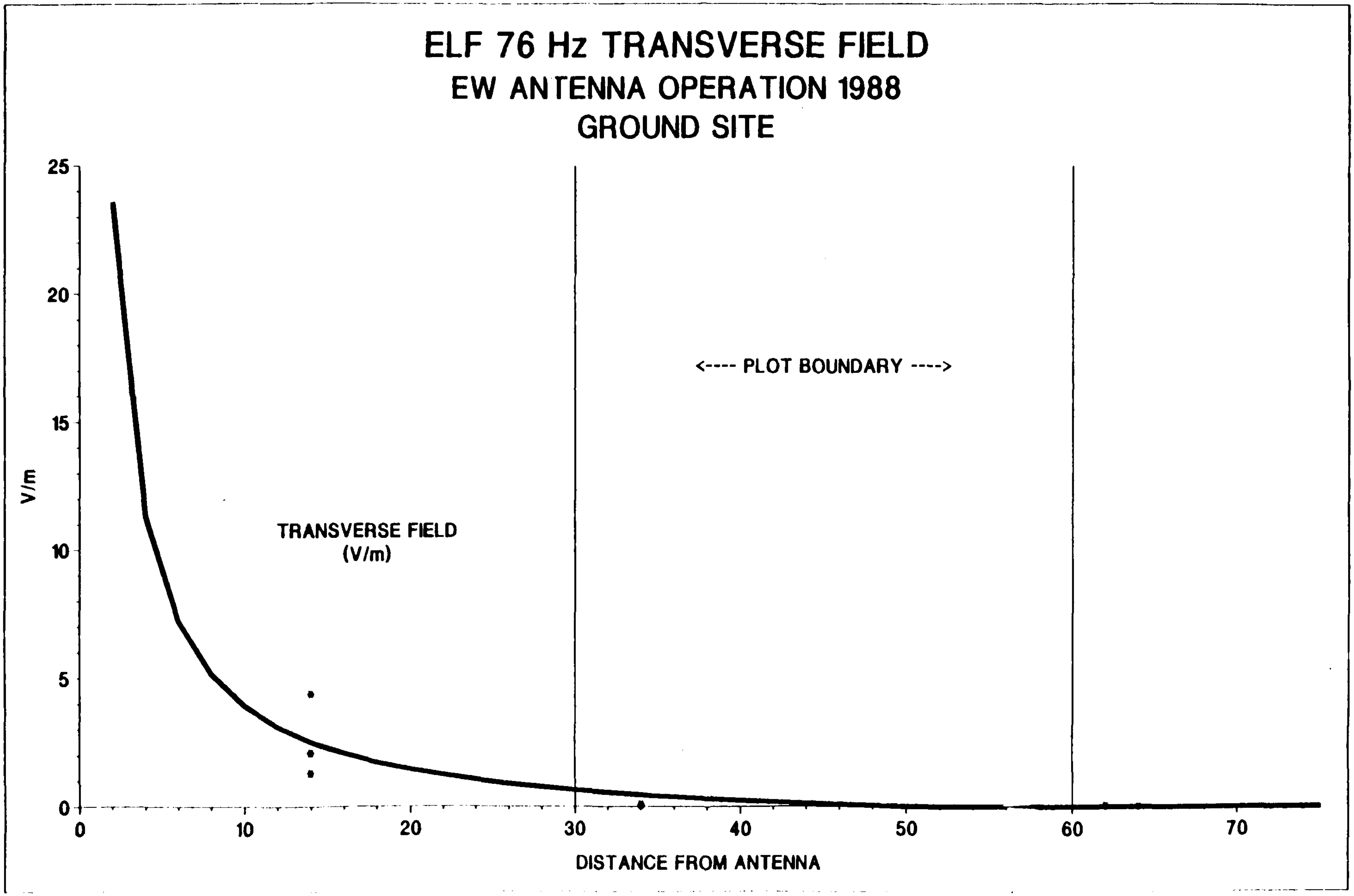
EW mG = -0.1052 + 22.834/X

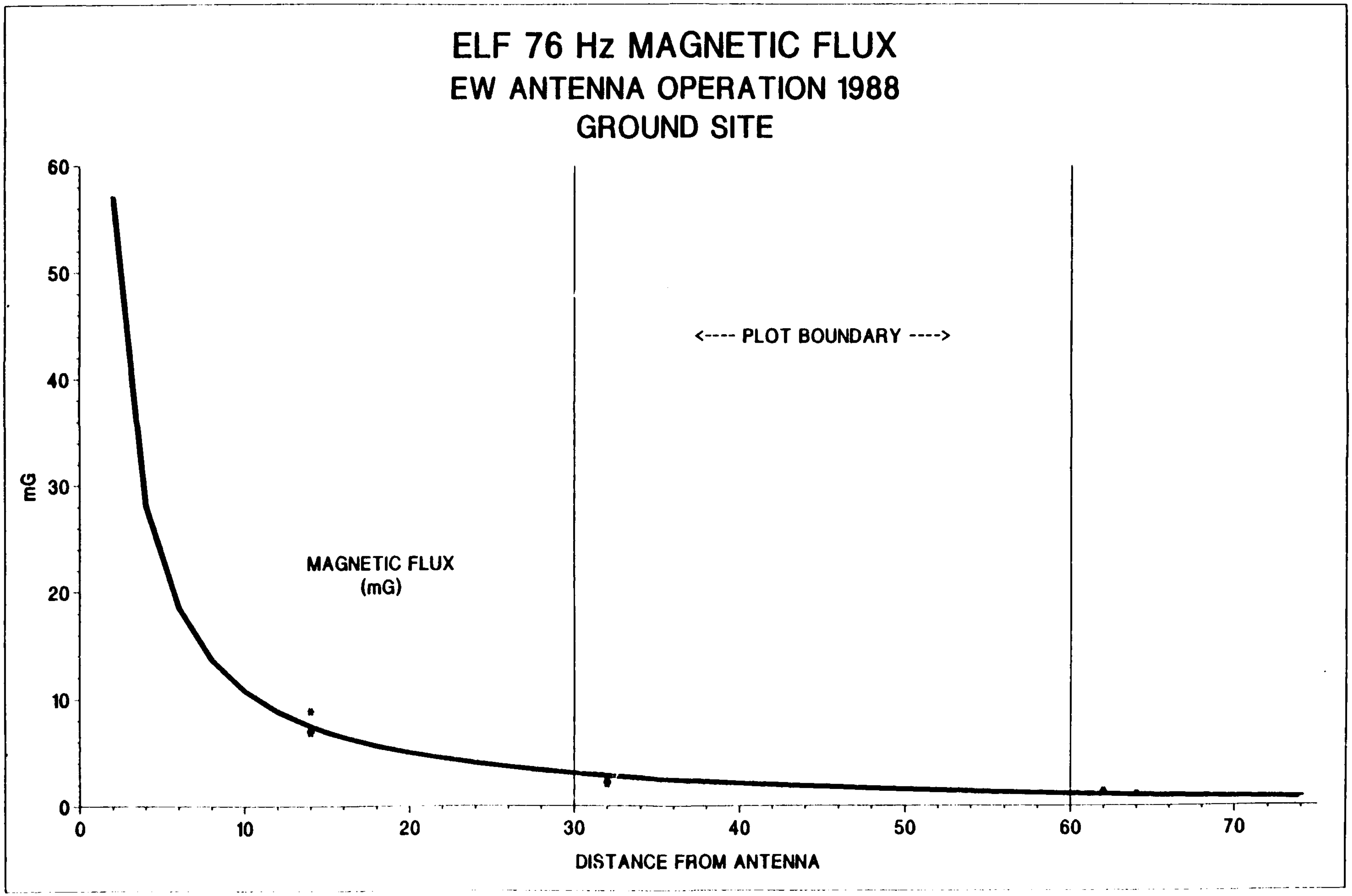
1988 NS mG = -0.0113 + 2.3432/X

EW mG = -0.7011 + 115.8912/X

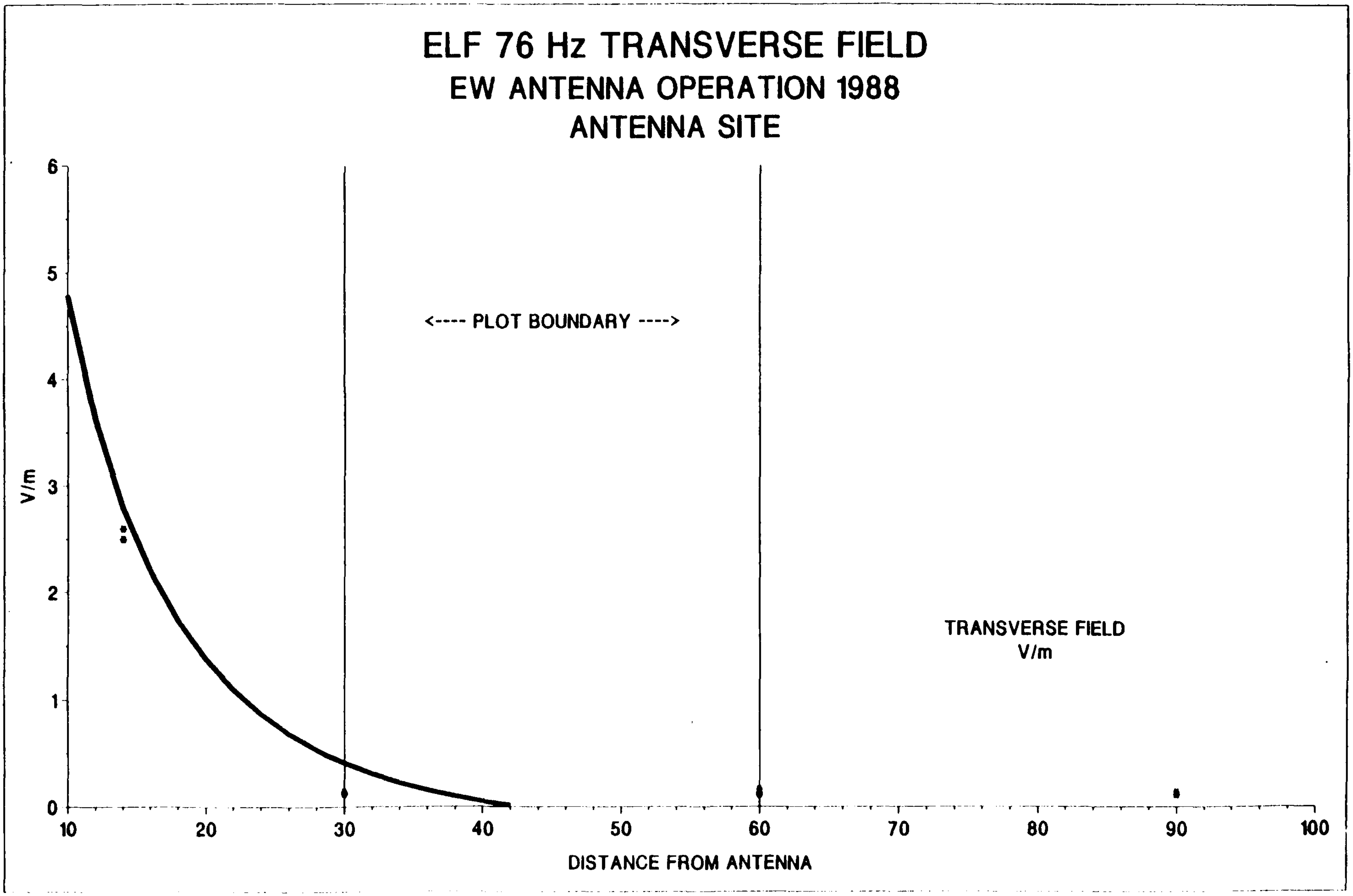
ELF 76 Hz LONGITUDINAL FIELD
EW ANTENNA OPERATION 1988
GROUND SITE



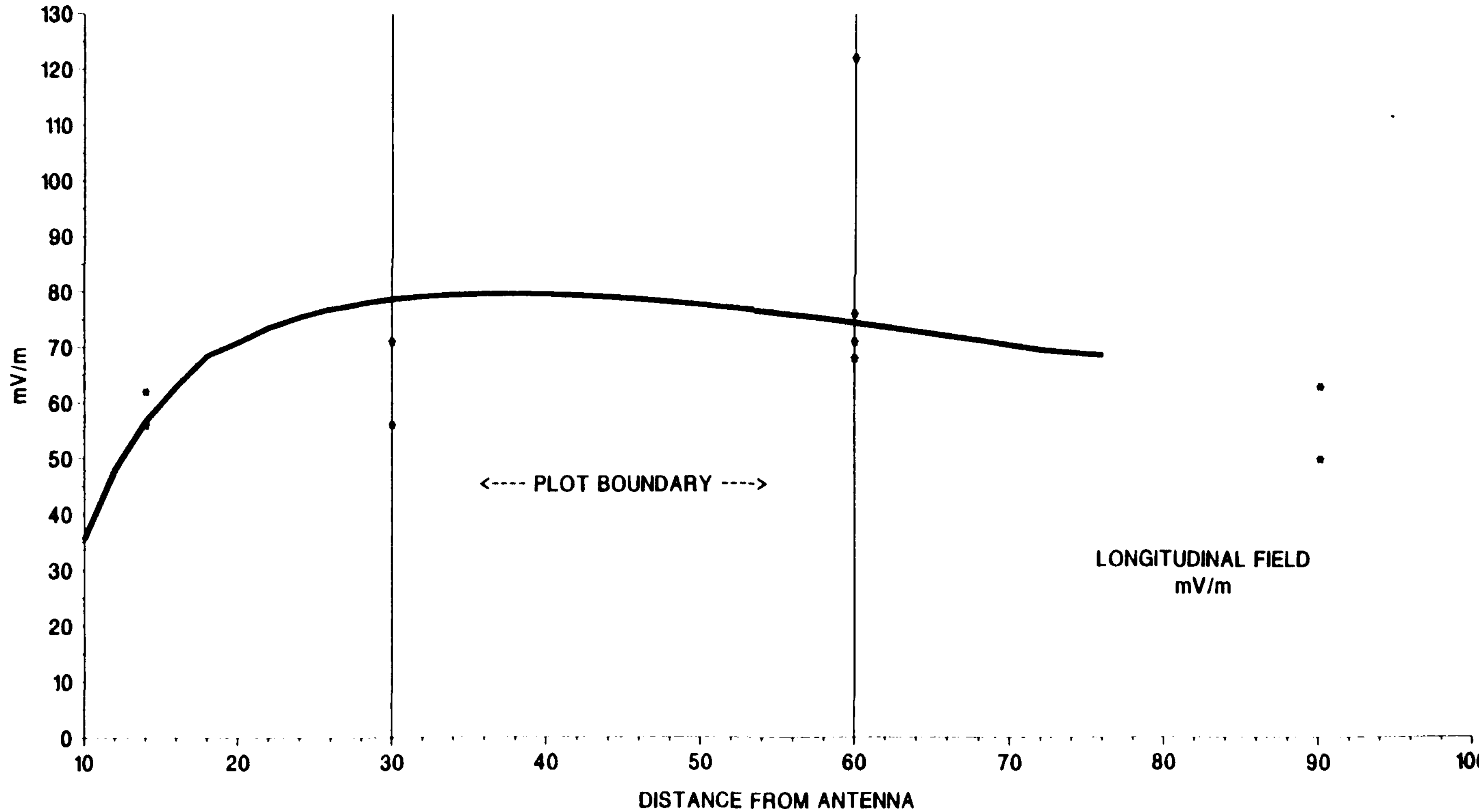

ELF 76 Hz TRANSVERSE FIELD
EW ANTENNA OPERATION 1988
GROUND SITE
<---- PLOT BOUNDARY ---->
TRANSVERSE FIELD
(V/m)
V/m
0
5
10
15
20
25
0
10
20
30
40
50
60
70
DISTANCE FROM ANTENNA

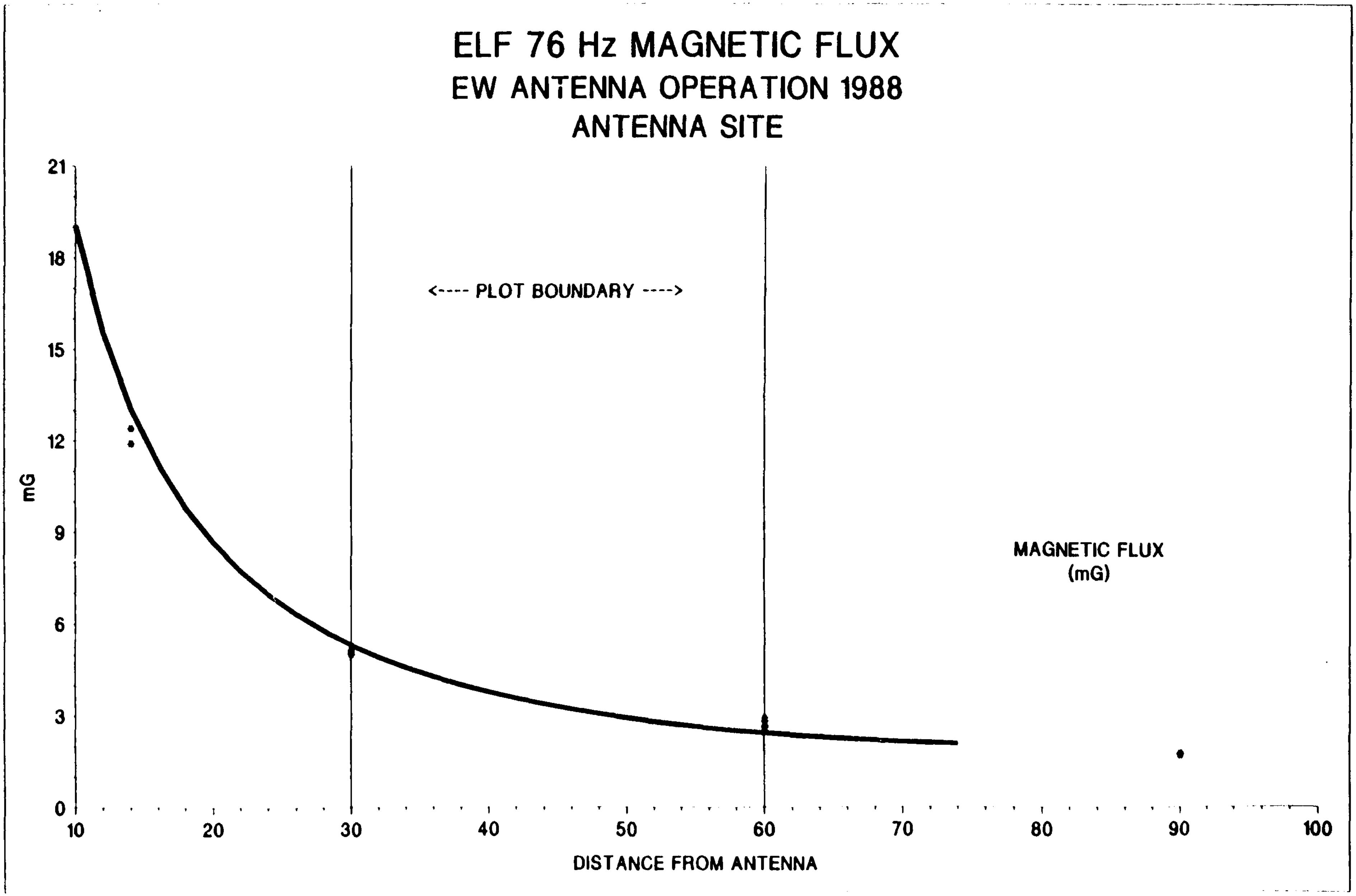


ELF 76 Hz MAGNETIC FLUX
EW ANTENNA OPERATION 1988
GROUND SITE
<---- PLOT BOUNDARY ---->
MAGNETIC FLUX
(mG)
mG
0
10
20
30
40
50
60
70
DISTANCE FROM ANTENNA


ELF 76 Hz TRANSVERSE FIELD
EW ANTENNA OPERATION 1988
ANTENNA SITE
<---- PLOT BOUNDARY ---->
TRANSVERSE FIELD
V/m
V/m
0
1
2
3
4
5
6
10
20
30
40
50
60
70
80
90
100
DISTANCE FROM ANTENNA

ELF 76 Hz LONGITUDINAL FIELD
EW ANTENNA OPERATION 1988
ANTENNA SITE




ELF 76 Hz MAGNETIC FLUX
EW ANTENNA OPERATION 1988
ANTENNA SITE
<---- PLOT BOUNDARY ---->
MAGNETIC FLUX
(mG)
mG
21
18
15
12
9
6
3
0
10
20
30
40
50
60
70
80
90
100
DISTANCE FROM ANTENNA

To: Glenn Mroz

Date: January 22, 1990

From: Dave Reed

CC: F. Cattelino
H. Liechty
P. Gale
B. Reed
M. Jurgensen
J. Bruhn

Subject: IITRI's response to our field exposure memo

I have gone over IITRI's comments to our memo. Several comments they made are due to the fact that there was a mistake in the transverse field equations for the [illegible] A site which were corrected in the memo of November [illegible], 1989. They did not have the benefit of the correct equations when they did their evaluation.

I have attached plots of the interpolated field equations with IITRI's observed field strengths (IITRI Technical Report E06595-5). Many of the responses given below to IITRI's specific comments will refer to these graphs.

In response to the comment that there is a small number of polynomial terms in the equations this is obviously true. However, given the noise in the measurements the curve should obviously be estimated using statistical means (note the variability in the plotted measurements on the graphs). We used all the measurements we had available from IITRI's technical report cited above. A statistician would tell you that we went way beyond the capabilities of the data when we estimated the two, three, or four terms in the equations we have from a dozen or fewer data points available at a site in any one year. There is a rule of thumb that says you should have 30 points per estimated coefficient; we had between 3 and 5 so it is actually pretty amazing the equations work as well as they do.

We did not have the 1989 measurements available to us at the time these equations were developed. We will, of course, take all available measurements into account when estimating 1989 exposure levels. If sufficient observations were available, we could test for differences between the measurement points in the plantations and the hardwood stands. From the figure in IITRI's letter, they put in a transect of points across the plantation but there is no such transect indicated in the hardwood stands. We would welcome any input as to how to incorporate seasonal changes in soil conductivity into account (we would welcome someone doing all of this and giving us equations to use in interpolation but, at the Traverse City meeting in 1988, we were told it was up to us to do this).

From the graph of magnetic flux, you can see that the interpolation equations we use represent the observations from 1988 fairly well. I do not see a need to revise these at this time.

From the beginning, we have indicated that we would need to be able to do this sort of interpolation in order to evaluate the effect of EM fields on the study sites; this is the primary purpose of the modeling efforts in the growth studies. This goes back at least to the Traverse City meeting and did not begin with the observations on aspen growth. In any case, we feel that questions concerning the extent and importance of increased growth should be addressed by individuals knowledgable in forest growth.

Confidence limits can be placed on the interpolated values at any point in the plots. A rough 95 % confidence limit at the mean distance from the antenna can be calculated by multiplying the square root of the mean square error given in our memo divided by the number of observed data points at a site by two. For the transverse, longitudinal, and magnetic fields, respectively, we get 0.043 V/m, 3.483 mV/m, and 0.052 mG at the antenna site. These values roughly correspond to 33 %, 5 %, and 2 % of the predicted values and are certainly far less than the year to year variation in the field intensities between 1986, 1987, and 1988. Whether or not they are good enough needs to be evaluated by the engineers as well as us. For now, the magnetic flux and longitudinal field intensity seem to be in pretty good shape while the transverse field needs work. This is borne out on the attached graphs as discussed below. At the ground site, all three interpolations seem to fit the observations rather well.

Regarding the specific comments on the later pages of IITRI's memo:

1. The terms "coupling" and "reradiated" are obviously more correct and we will use these in further discussions in the annual report and elsewhere.

2. Comments on the 60 Hz fields are true: we will use the information from IITRI's Technical Report when we do anything for external distribution.

3. The fact that field intensity is independent of operating frequency makes our life much easier and we are thankful for this clarification. The comments on longitudinal field are also well taken; on the attached graph, you can see that the observations of longitudinal field are the noisiest of the three fields measured.

4. We do not see any differences in the measured values of transverse field intensities between the hardwood and the plantation points in the 1988 measurements. On the attached graph, you can see that all measurements at 60 m from the antenna are grouped together. If more measurements become available to allow us to quantify differences between the hardwood and plantation points we will do so. We need more data points to be able to estimate this.

5. The value of additional measurements throughout the year would come from improvements in our ability to interpolate exposure levels across the sites. I will leave it to the engineers to judge the adequacy of our abilities to do this now. They are best able to judge if we need help here or not. The planned use of such measurements would be to improve these interpolations. I just do not know the variability across a year in order to judge the benefits of continuous monitoring. The equations we have now fit the measurements, which were taken at a single time in each growing season, rather well. I do not know what sort of variability there is within a year, between years there is qeite a difference which is reflected in our interpolations and I would expect within year variation to be less than between year variation.

6. We will deal with the non-independent operation of the NS and EW legs of the antenna when we have measured values from 1989; over the time covered in the IITRI technical report, the legs operated independently and are represented that way in the equations here.

7. As mentioned above, the equations in the original memo for transverse fields at the antenna site were incorrect and the correct equations were given in the later memo. Predicted field intensities and observed values for all three field types at the antenna and ground sites are given in the attached figures. The transverse field is the most uniform across the plots at the antenna site and our equations tend to overestimate at the edge of the plots near the antenna and underestimate at the other side of the plots. Longitudinal field appears to be very variable at the antenna site while the magnetic flux appears to be predictable. All three fields seem predictable at the ground site, at least when comparing the interpolated values to IITRI's measurements.

In conclusion, I think we did a reasonable job on interpolating the fields across the plots given the data available from IITRI's measurements. I would very much prefer someone familiar with EM fields to give us interpolation equations for each year. We were told, however, not to expect this. Until we have better methods, we will continue to use the internolated values from these

equations in our analyses for the report. In the report, these interpolated field intensities will be used in the covariate analyses to see if differences in field intensity can account for differences in ecosystem measures that are not accounted for by the ambient covariates. They will also be used in the modeling work, primarily by looking at correlations between the field intensities and the residuals from the models. The details of these comparisons will vary by element of course with more information to be given in the annual report.

APPENDIX B

Climatic monitoring information

Table 1 Missing data equations 1989.

1989 Missing Data Equations

Plot	Equation	$\bar{Y}$	Standard Error	R2	Confidence Interval at X1, X2
	Soil Temperature Ground Plantation Plots (5 cm)				
1	$Y = .606(X_1)+.908(X_2)-3.094$	12.5	.049	.990	Y±.08
2	$Y = -.148(X_1)+.935(X_2)+1.091$	12.9	.043	.992	Y±.07
3	$Y = .636(X_1)+.910(X_2)-2.809$	13.0	.049	.990	Y±.08

X_1 = month of year (i.e...6,7,8)
X_2 = average daily soil temperature 5 cm on antenna site
Y = average daily soil temperature 5 cm on ground site

Plot	Equation	$\bar{Y}$	Standard Error	R2	Confidence Interval at X1, X2
	Soil Temperature Ground Plantation Plots (10 cm)				
1	$Y = -1.200(X_1)+1.025(X_2)+5.279$	12.6	.094	.961	Y±.16
2	$Y = -1.227(X_1)+.975(X_2)+5.617$	12.1	.097	.953	Y±.17
3	$Y = -.202(X_1)+.912(X_2)+1.435$	12.7	.095	.958	Y±.16

X_1 = month of year (i.e...6,7,8)
X_2 = average daily soil temperature 10 cm on antenna site
Y = average daily soil temperature 10 cm on ground site

Plot	Equation	$\bar{Y}$	Standard Error	R2	Confidence Interval at X1, X2
	Soil Moisture Ground Plantation Plots (5 cm)				
1	$Y = -.033(X_1)+1.127(X_2)-.045$	13.9	.165	.548	Y±.28
2	$Y = -.445(X_1)+.728(X_2)+5.521$	12.0	.098	.615	Y±.17
3	$Y = -1.391(X_1)+1.304(X_2)+7.256$	15.6	.216	.552	Y±.37

X_1 = month of year (i.e...6,7,8)
X_2 = average daily soil moisture 5 cm on antenna site
Y = average daily soil moisture 5 cm on ground site

Table 3 Missing data equations 1989.

1989 Missing Data Equations

Plot	Equation	$\bar{Y}$	Standard Error	R2	Confidence Interval at X1, X2
	Soil Temperature Antenna Plantation Plots (10 cm)				
1	$Y = .987(X_1)+.078$	4.0	.029	.998	Y±.05
2	$Y = 1.069(X_1)-.385$	10.7	.078	.987	Y±.13
3	$Y = 1.147(X_1)-.042$	11.9	.164	.953	Y±.28
	X_1 = average daily soil temperature 10 cm on ground site; Y = average daily soil temperature 10 cm on antenna plantation plots				
	Soil Temperature Antenna Hardwood Plots (10 cm)				
1	$Y =-.344(X_1)+.988(X_2)+.404$	3.4	.034	.997	Y±.06
2	$Y = .974(X_2)-1.293$	8.8	.068	.988	Y±.12
3	$Y = 1.049(X_2)-2.407$	8.5	.137	.960	Y±.23
	X_1 = month of year (i.e...6,7,8); X_2 = average daily soil temperature 10 cm on ground site; Y = average daily soil temperature 10 cm at antenna hardwood plots				
	Relative Humidity Antenna Site				
	$Y = 1.224(X_1)$	91.4	1.426	.994	Y±2.42
	X_1 = daily relative humidity at ground site; Y = daily relative humidity at antenna site				
	Antenna Average Vegetation Temperature (30 cm)				
	$Y = 1.013(X_1)-.331$	10.2	.060	.997	Y±.10
	X_1 = average daily air temperature at antenna hardwood site; Y = average vegetation temperature at antenna site				
	Control Average Vegetation Temperature (30 cm)				
	$Y = .959(X_1)+.421$	11.9	.102	.972	Y±.17
	X_1 = average daily air temperature at control hardwood site; Y = average vegetation temperature at control site				

Table 2 Missing data equations 1989.

1989 Missing Data Equations

Plot	Equation	$\bar{Y}$	Standard Error	R^2	Confidence Interval at X1, X2
	Soil Moisture Ground Plantation Plots (10 cm)				
1	$Y = 5.930(X_1)+2.076(X_2)-41.217$	17.2	.266	.816	Y±.45
2	$Y =-.285(X_1)+.789(X_2)+5.319$	13.6	.096	.593	Y±.16
3	$Y =-.766(X_1)+.359(X_2)+14.736$	15.0	.151	.168	Y±.26

X_1 = month of year (i.e...6,7,8)
X_2 = average daily soil moisture 10 cm on antenna site
Y = average daily soil moisture 10 cm on ground site

Plot	Equation	$\bar{Y}$	Standard Error	R^2	Confidence Interval at X1, X2
	Soil Temperature Antenna Plantation Plots (5 cm)				
1	$Y = .100(X_1)+.990(X_2)-.217$	4.2	.025	.999	Y±.04
2	$Y = 1.078(X_2)-.424$	11.1	.071	.990	Y±.12
3	$Y = 1.191(X_2)-.487$	12.2	.179	.950	Y±.31

X_1 = month of year (i.e...6,7,8)
X_2 = average daily soil temperature 5 cm on ground site
Y = average daily soil temperature 5 cm on antenna plantation plots

Plot	Equation	$\bar{Y}$	Standard Error	R^2	Confidence Interval at X1, X2
	Soil Temperature Antenna Hardwood Plots (5 cm)				
1	$Y =-.311(X_1)+1.002(X_2)-.127$	3.2	.033	.997	Y±.06
2	$Y = 1.014(X_2)-1.513$	9.3	.072	.988	Y±.12
3	$Y = .996(X_2)-1.738$	8.9	.101	.977	Y±.17

X_1 = month of year (i.e...6,7,8)
X_2 = average daily soil temperature 5 cm on ground site
Y = average daily soil temperature 5 cm on antenna hardwood plots

Figure 1. Kjeldahl nitrogen content plotted by month.

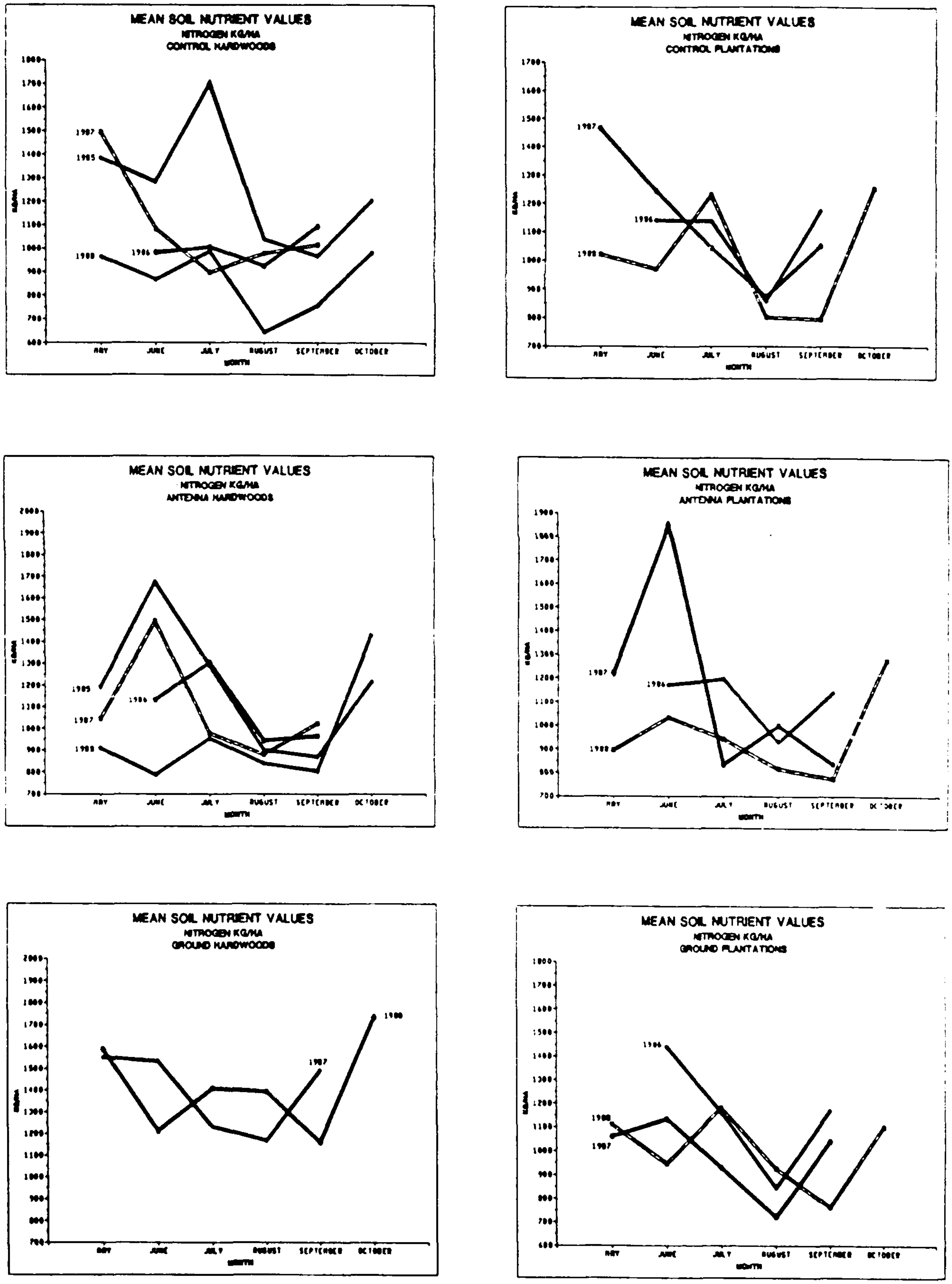


Figure 2. Total phosphorus content plotted by month.

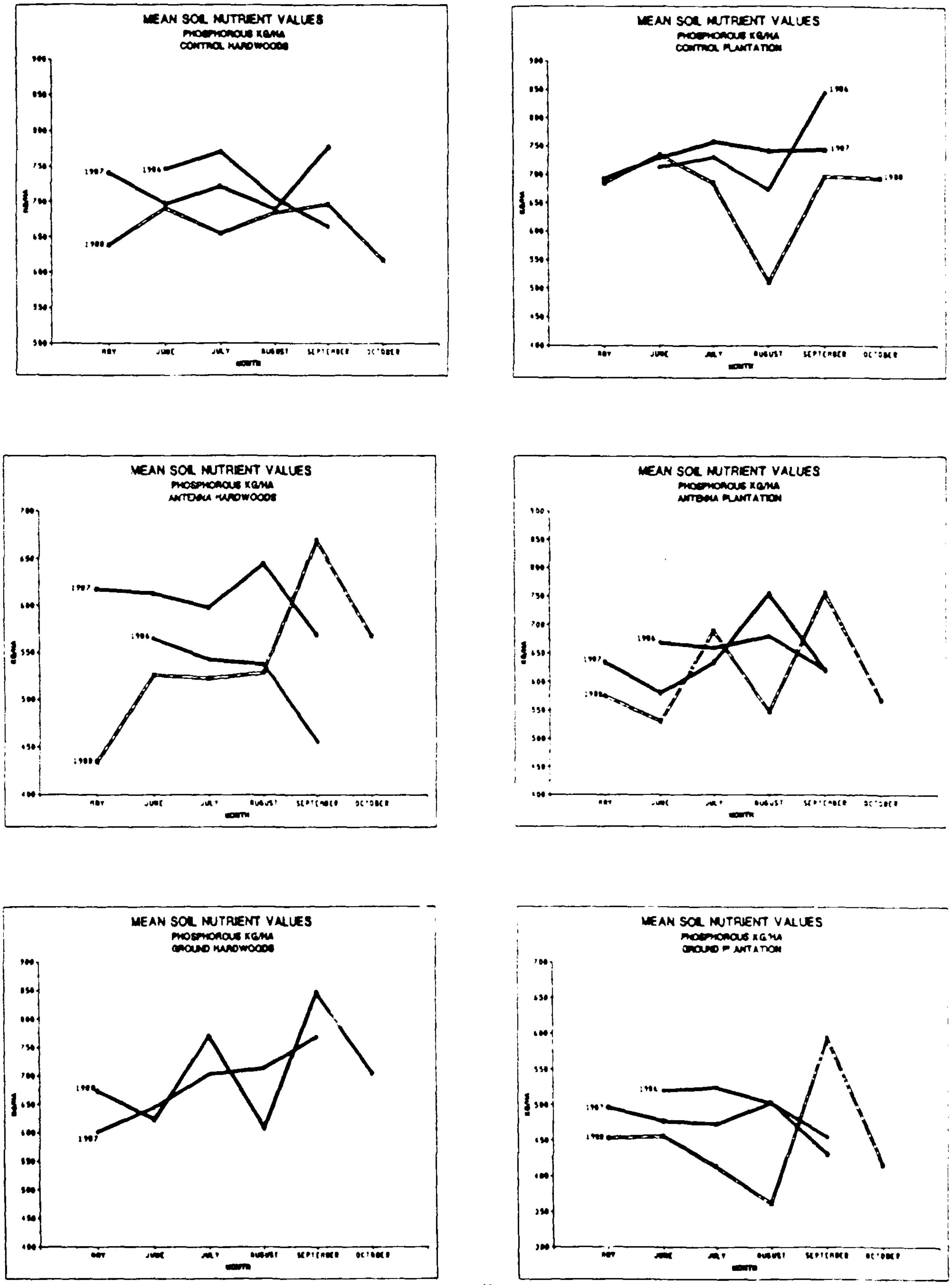


Figure 3. Exchangeable calcium content plotted by month.

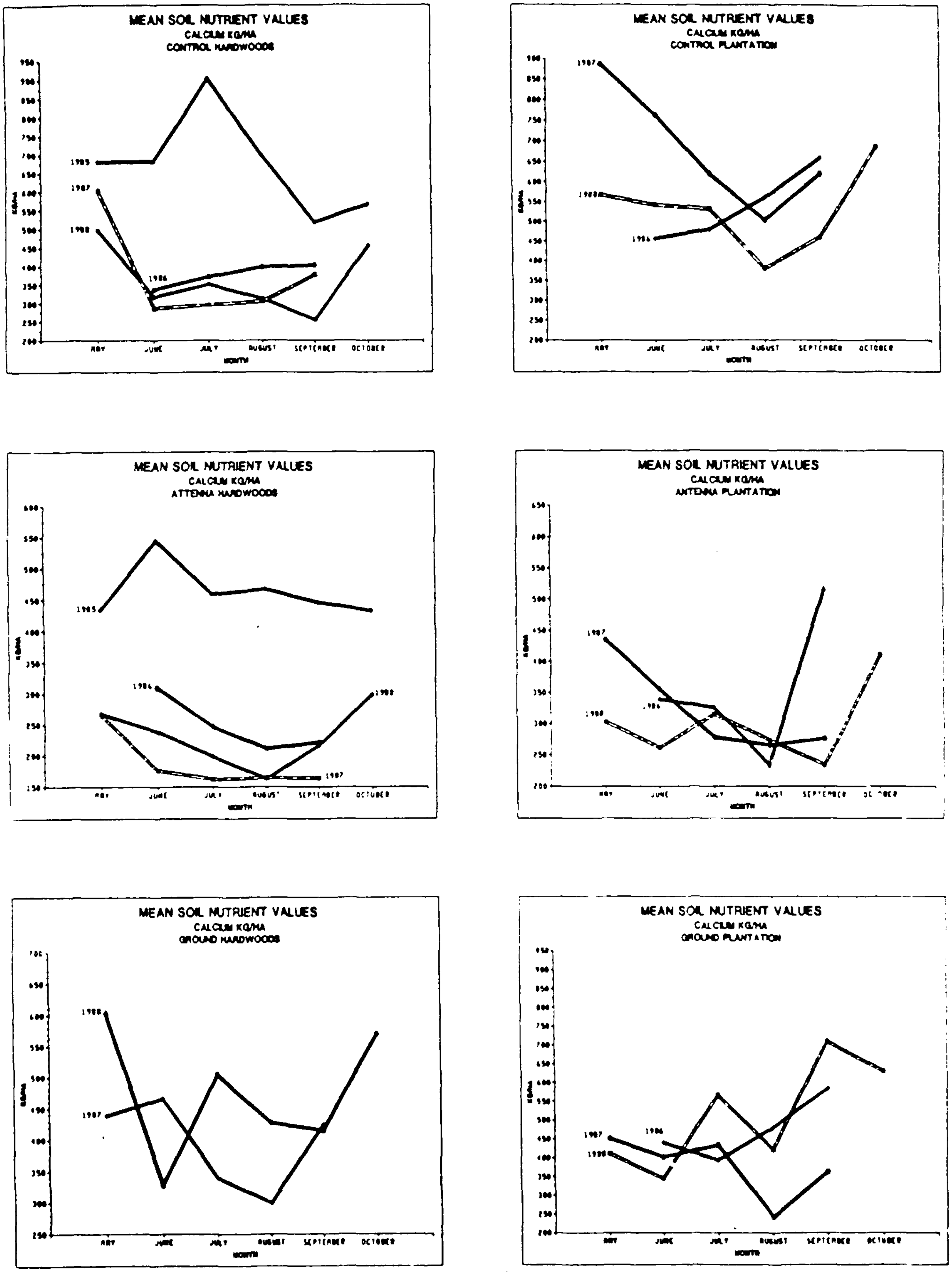


Figure 4. Exchangeable magnesium content plotted by month.

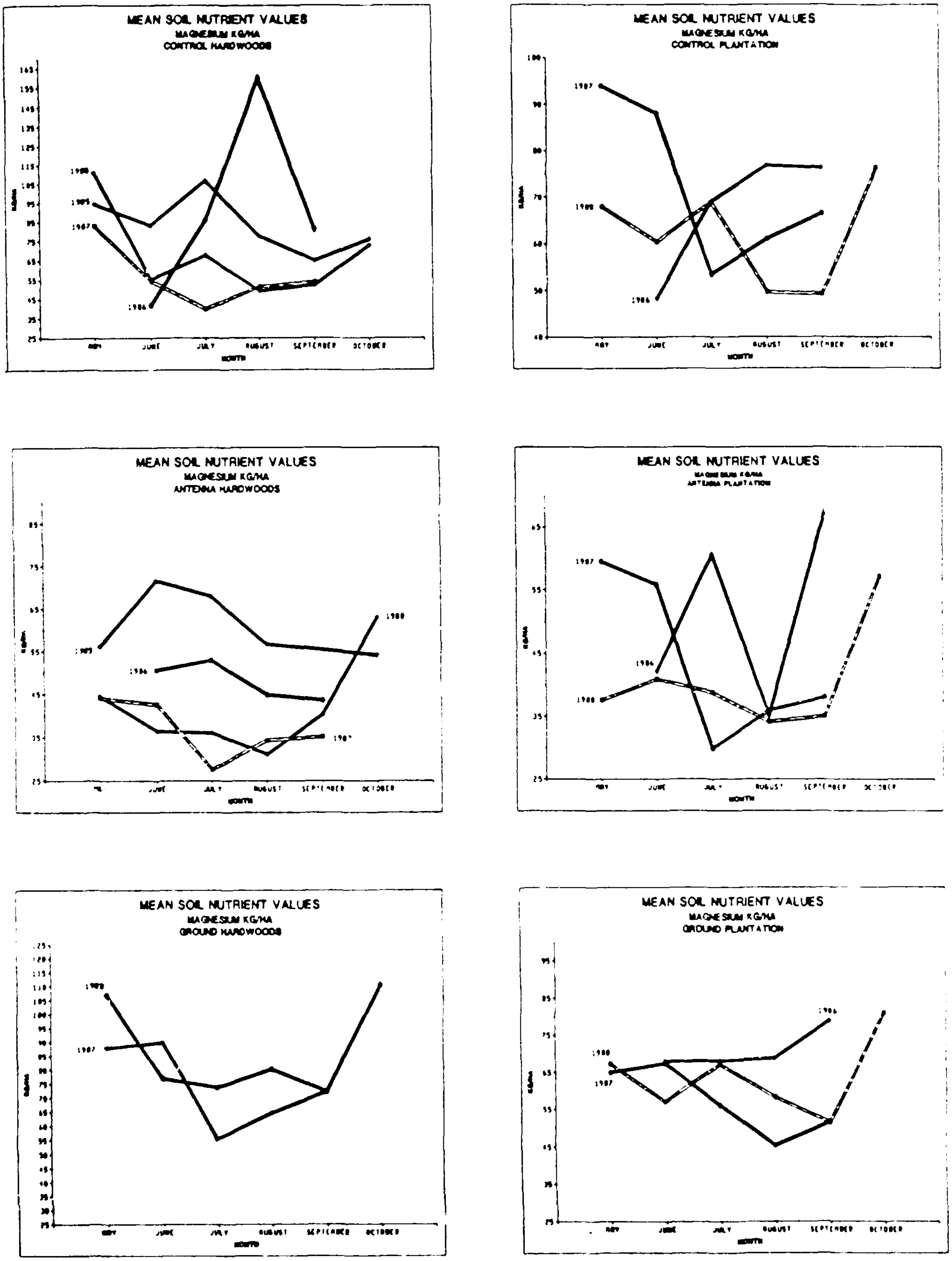


Figure 5. Exchangeable potassium content plotted by month.

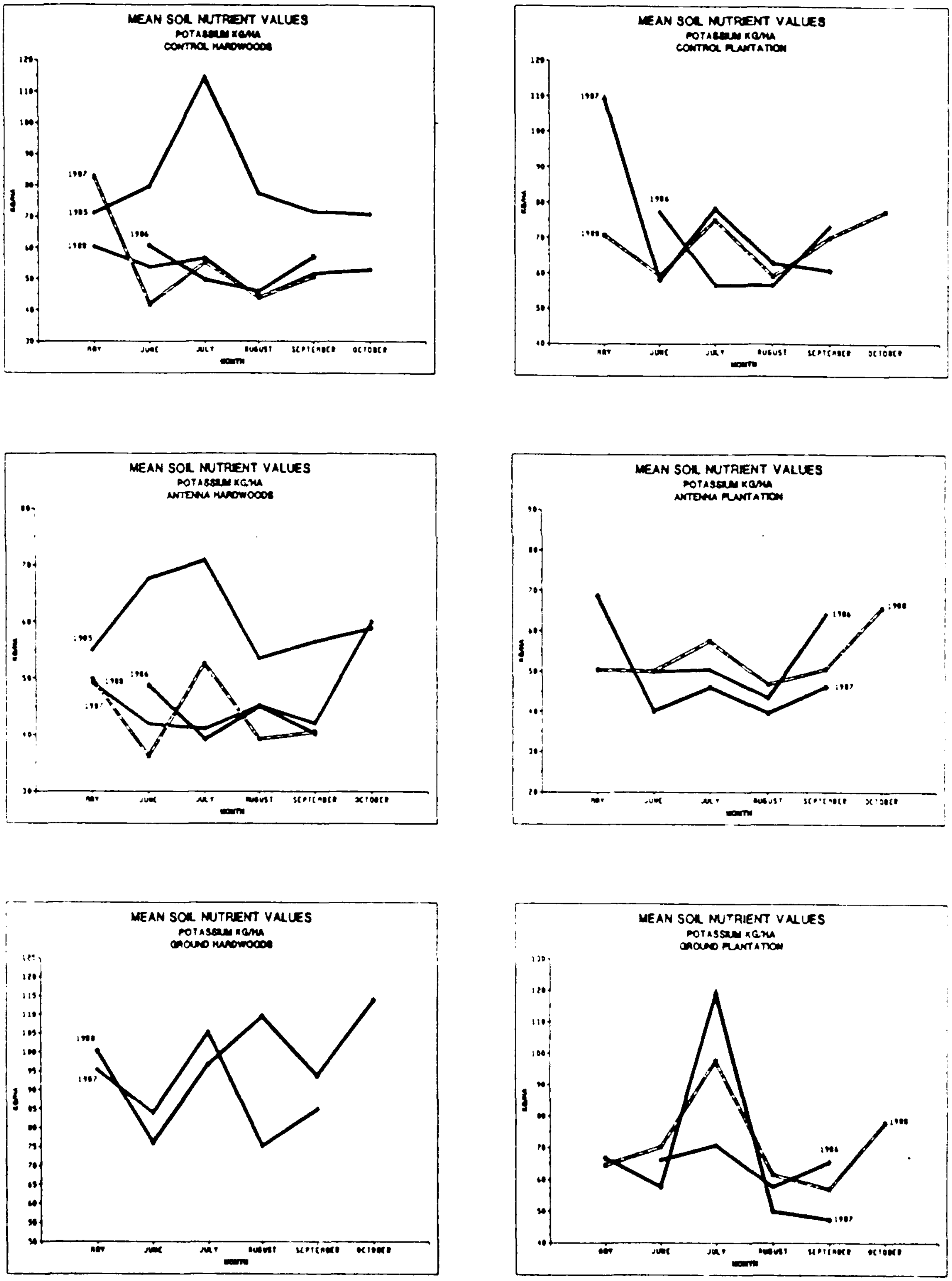


Table 4. Mean soil nutrient values (kg/ha) Ground Hardwoods 1985-1988

	GROUND[a]									
	1987					1988				
	Ca	Mg	K	P[c]	N	Ca	Mg	K	P[c]	N
May	439.33	88.02	95.28	601.98	1551.74	602.34	106.95	100.34	673.40	1587.57
Jun	466.75	90.03	83.93	644.48	1532.59	328.32	76.92	76.14	623.19	1212.86
Jul	339.99	55.43	105.41	703.23	1232.12	504.24	73.84	96.90	769.81	1407.62
Aug	299.08	64.68	75.24	713.75	1168.04	427.21	80.29	109.57	608.76	1392.25
Sep	424.83	72.39	84.90	768.48	1490.11	415.42	72.27	93.82	845.44	1160.34
Oct	-	-	-	-	-	569.64	110.52	113.89	704.74	1733.97

a Sampling of Hardwood plots at Ground was initiated in 1987.
b Water soluble P
c Total P

Table 4. Cont. Mean soil nutrient values (kg/ha) Antenna Hardwoods 1985-1988

ANTENNA

	1985					1986				
	Ca	**Mg**	**K**	**P[b]**	**N**	**Ca**	**Mg**	**K**	**P[c]**	**N**
May	433.79	56.09	54.98	2.71	1193.57	-	-	-	-	-
Jun	545.04	71.58	67.67	2.63	1672.95	310.01	50.62	48.69	564.56	1132.92
Jul	459.66	67.96	70.91	3.00	1290.39	246.89	52.93	39.22	542.35	1303.99
Aug	466.99	56.72	53.50	2.52	900.67	211.37	44.84	45.00	537.81	944.21
Sep	445.95	55.45	56.51	1.83	868.69	221.70	43.61	40.23	456.09	965.75
Oct	432.36	54.15	58.86	2.78	1214.97	-	-	-	-	-

	1987					1988				
	Ca	**Mg**	**K**	**P[c]**	**N**	**Ca**	**Mg**	**K**	**P[c]**	**N**
May	264.99	44.03	49.79	617.66	1046.31	267.49	44.45	49.10	434.51	908.64
Jun	176.20	42.57	36.25	613.01	1492.42	238.35	36.42	41.90	526.09	786.50
Jul	162.18	27.56	52.55	597.86	978.10	198.52	36.04	41.09	522.68	954.10
Aug	164.24	34.33	39.22	644.44	879.63	162.69	31.06	45.15	529.09	839.01
Sep	163.80	35.20	40.52	569.24	1023.40	215.80	40.38	42.02	668.82	803.35
Oct	-	-	-	-	-	298.16	62.94	60.04	567.87	1426.50

b Water soluble P
c Total P

Table 4. Cont. Mean soil nutrient values (kg/ha) Control Hardwoods 1985-1988

CONTROL

	1985					1986				
	Ca	Mg	K	P^b	N	Ca	Mg	K	P^c	N
May	681.04	94.50	71.06	2.17	1384.12	-	-	-	-	-
Jun	683.10	83.34	79.49	2.47	1282.08	336.80	41.89	60.53	746.19	982.53
Jul	904.92	107.00	114.41	4.59	1701.63	371.76	86.08	49.59	770.28	1005.18
Aug	698.71	77.54	77.14	2.61	1037.65	398.40	160.14	45.82	704.46	923.25
Sep	519.04	64.97	71.35	2.22	966.23	402.91	81.42	57.02	664.56	1091.92
Oct	566.70	76.03	70.52	2.76	1201.93	-	-	-	-	-

	1987					1988				
	Ca	Mg	K	P^c	N	Ca	Mg	K	P^c	N
May	601.69	82.94	82.44	740.53	1494.04	495.79	110.87	60.18	638.36	964.23
Jun	285.93	54.12	41.77	696.56	1081.69	316.50	55.19	53.72	690.45	866.93
Jul	295.83	39.95	55.12	720.62	896.95	351.02	67.66	56.55	654.11	987.58
Aug	305.23	51.43	43.88	688.24	978.14	311.87	49.19	43.71	684.45	643.16
Sep	377.66	53.99	50.46	777.02	1014.04	255.10	52.54	51.53	695.90	756.53
Oct	-	-	-	-	-	454.93	72.83	52.79	616.09	979.99

b Water soluble P
c Total P

Table 4. Cont. Mean soil nutrient values (kg/ha) Ground Plantation 1985-1988

GROUND

	1985					1986				
	Ca	Mg	K	P[b]	N	Ca	Mg	K	P[c]	N
May	-	-	-	-	-	-	-	-	-	-
June	-	-	-	-	-	438.97	68.04	66.19	520.07	1439.19
Jul	1058.32	120.45	118.91	3.53	1869.81	393.43	68.11	70.88	523.75	1159.94
Aug	-	-	-	-	-	479.76	68.89	57.89	501.93	845.06
Sep	-	-	-	-	-	583.92	79.02	65.69	454.77	1168.39

	1987					1988				
	Ca	Mg	K	P[c]	N	Ca	Mg	K	P[c]	N
May	450.51	65.06	66.71	495.95	1059.76	409.91	67.31	64.58	453.19	1109.80
Jun	401.64	67.45	57.74	476.77	1132.84	344.87	57.07	70.27	455.47	945.85
Jul	433.26	56.08	119.09	472.77	928.65	566.13	67.10	97.74	412.61	1180.93
Aug	242.93	45.42	50.01	502.39	722.00	421.34	58.27	61.70	361.17	925.51
Sep	362.81	51.67	47.37	430.52	1040.38	709.85	51.47	57.02	593.38	763.25
Oct	-	-	-	-	-	630.03	80.99	77.98	416.15	1100.13

b Water soluble P
c Total P

Table 4. Cont. Mean soil nutrient values (kg/ha) Antenna Plantation 1985-1988

ANTENNA

	1985					1986				
	Ca	**Mg**	**K**	**P[b]**	**N**	**Ca**	**Mg**	**K**	**P[c]**	**N**
May	-	-	-	-	-	-	-	-	-	-
Jun	-	-	-	-	-	339.10	42.18	49.98	667.71	1171.12
Jul	637.70	82.02	89.76	3.85	1539.19	326.02	60.57	50.41	658.81	1195.71
Aug	-	-	-	-	-	233.15	35.13	43.39	679.29	929.81
Sep	-	-	-	-	-	515.17	67.05	64.00	620.12	1138.27

	1987					1988				
	Ca	**Mg**	**K**	**P[c]**	**N**	**Ca**	**Mg**	**K**	**P[c]**	**N**
May	434.78	59.50	68.62	633.37	1220.57	302.51	37.61	50.38	574.68	895.10
Jun	356.22	55.81	40.14	580.07	1848.89	261.32	40.94	50.03	530.17	1033.15
Jul	277.70	29.85	46.01	633.38	833.67	315.19	38.76	57.53	688.84	942.83
Aug	264.88	35.93	39.66	753.05	998.80	273.45	34.10	46.80	546.97	815.73
Sep	275.97	38.13	46.14	619.82	836.46	233.95	35.07	50.54	754.83	773.35
Oct	-	-	-	-	-	410.19	57.10	65.65	567.63	1275.19

b Water soluble P
c Total P

Table 4. Cont. Mean soil nutrient values (kg/ha) Control Plantation 1985-1988

CONTROL

	1985					1986				
	Ca	Mg	K	P^b	N	Ca	Mg	K	P^c	N
May	-	-	-	-	-	-	-	-	-	-
Jun	-	-	-	-	-	456.21	48.27	77.38	713.35	1141.23
Jul	1051.32	112.44	101.94	3.27	1853.58	478.55	68.99	56.50	730.90	1138.57
Aug	-	-	-	-	-	558.00	76.77	56.62	673.86	858.73
Sep	-	-	-	-	-	655.21	76.33	73.32	844.44	1175.67

	1987					1988				
	Ca	Mg	K	P^c	N	Ca	Mg	K	P^c	N
May	885.37	93.98	109.12	693.03	1465.86	565.94	67.91	70.82	684.92	1020.37
Jun	760.34	88.02	58.27	730.08	1245.42	540.32	60.35	59.47	735.28	969.39
Jul	616.87	53.36	78.20	758.08	1043.89	529.66	68.85	74.97	685.97	1231.62
Aug	501.45	61.07	62.91	741.97	874.30	379.37	49.61	59.20	510.60	801.97
Sep	616.92	66.53	60.78	744.44	1053.35	459.09	49.26	70.14	696.90	795.42
Oct	-	-	-	-	-	682.49	76.43	77.59	694.01	1254.64

b Water soluble P
c Total P

APPENDIX C

Red pine leaf water potential 1985 - 1989

Average leaf water potential of red pine seedlings 1985-1988 (-MPa). N=15.

Week of	1985 Ground	1985 Antenna	1985 Control	1986 Ground	1986 Antenna	1986 Control
5/25	2.32	2.17	1.10	.68	.77	.70
6/10	--	--	--	.62	.68	.80
6/24	.50	.50	.64	.73	.86	.74
7/8	--	--	--	.66	.72	.74
7/22	.63	.65	.68	.59	.63	.93
8/5	--	--	--	.45	.46	.62
8/19	.59	.57	.64	.37	.39	.56
9/2	--	--	--	.39	.36	.47
9/20	1.94	2.15	2.25	--	--	--

Week of	1987 Ground	1987 Antenna	1987 Control	1988 Ground	1988 Antenna	1988 Control
5/25	.23	.26	.24	.59	.52	.45
6/10	.19	.20	.19	.28	.21	.32
6/24	.23	.15	.24	.53	.38	.40
7/8	.26	.26	.50	.57	.41	.52
7/22	.25	.19	.21	.67	.47	.69
8/5	.42	.27	.43	.27	.23	.39
8/19	.54	.66	.43	.24	.35	.28
9/2	.81	.65	.75	.35	.45	.66
9/20	.77	.69	.62	--	--	--

Week of	1989 Ground	1989 Antenna	1989 Control
5/25	.27	.20	.66
6/10	.75	.68	.67
6/24	.39	.44	.97
7/8	.46	.38	.35
7/22	.42	.26	.52
8/5	.79	.82	.62
8/19	.19	.16	.45
9/2	.75	.69	.30

Note: Xylem water was frozen during the weeks of 5/25 and 9/20 1985 which results in artificially high PMS values.

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ABSTRACT

Five full years of experience with red pine, northern red oak, and red maple foliar litter decomposition have been completed on all three study units. The experimental sample units consist of 1) bagged bulk foliage samples of each litter species, for determination of both dry matter mass loss and nutrient flux, and 2) bagged individual fascicle/leaf samples, for more precise characterization of dry matter mass loss.

Precision in the raw data sets has generally been highest in the hardwood stand subunits. Among the three study species, pine has provided the most precise data, while maple data are least precise. Dry matter mass loss data are more precise than nutrient data. Our experimental design is clearly powerful enough to identify very subtle differences in the rates and patterns of bulk and individual fascicle/leaf decomposition, especially in the hardwood stand subunits.

Covariates have proven to be useful for explaining differences detected by ANOVA in dry matter mass loss among hardwood stands, plantations, and years. Useful covariates include total precipitation, precipitation event frequency, air and soil temperature degree days, and initial leaf density (for individual oak leaves). Weather-related covariates have not been as helpful as anticipated, probably because they are calculated independently of one another. Two approaches are being taken to remedy this. First, at least one covariate related to AET (actual evapotranspiration) will be constructed to simultaneously consider temperature, precipitation and surface soil water-holding capacity. Second, an alternative dependent variable (δX) is being constructed, to permit evaluation of periodic decomposition progress during the annual experiments. Nutrient contents of retrieved litter samples are being evaluated for use as covariates to help explain dry matter mass loss. Though initial nutrient content has not yet proven useful with the five-year data set, initial lignin content determinations have been completed and may prove helpful, particularly with the faster decomposing maple litter.

Emphasis in the Red Pine Rhizosphere Streptomycete work element during 1989 was focused on the enumeration and characterization of streptomycetes associated with the predominant mycorrhizal morphology type observed on red pine seedlings in the three plantations. Counts of both streptomycete levels and numbers of streptomycete morphotypes were made Representatives of each morphotype were further characterized, in particular for ability to degrade complex organic compounds.

Detectable differences for the 5-year data set using ANOVA were less than 1 percent for streptomycete levels and 9 percent for morphotype numbers. Significant differences were found among years and months, but not between plantations. For levels, the 1987 and 1988 values were significantly higher than those for 1985, 1986 and 1989; the October values were significantly lower

than for all other months. Morphotype numbers declined annually from 1985 through 1987, but levelled off in 1988 and remained level in 1989. May morphotype numbers were greater than those for all months except June, while those in October were lower than for all other months. Similar, relatively stable streptomycete populations appear to have become established at all three study plantations.

ANACOV for streptomycete levels, using air temperature degree days and precipitation frequencies and totals as covariates, explained all differences between years. A similar ANACOV for morphotype numbers, substituting soil temperature for air temperature, also explained several yearly differences (notably 1986 and 1987 vs. 1989). Monthly differences in morphotype numbers were all explained, but with greatly increased detectable differences.

Morphotype B was again detected at each plantation on each sampling date. The most notable decrease in incidence was of morphotype F, which had a high frequency of isolation in previous seasons. Of 109 isolates tested, representing all morphotypes detected during 1989, 69%, 70%, and 72% degraded calcium oxalate, cellulose, and lignocellulose, respectively. More than half of the isolates and morphotypes tested could degrade all three substrates. These results are similar to those obtained with 1987 and 1988 isolates, indicating little change in morphotype activities in the past three years.

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SUMMARY

Litter Decomposition and Nutrient Flux

Five full years of experience with red pine, northern red oak, and red maple foliar litter decomposition have been completed on all three study units (including 2 hardwood stand and 3 plantation subunits). An additional year of useful data for red pine was collected in 1983-84 at the antenna hardwood stand subunit, and the samples for the sixth complete study have been installed in the field. The experimental sample units consist of 1) bagged bulk foliage samples of each litter species, for determination of both dry matter mass loss and associated nutrient flux, and 2) bagged individual fascicle/leaf samples, for more precise characterization of dry matter mass loss patterns. Dry matter mass loss data sets are complete at this time. Nutrient (N, P, K, Ca, and Mg) data sets for the 1983-84, 1984-85, and 1985-86 studies are complete. The nutrient data sets for alternate months (May, July, September, and November) are complete from the 1986-87 and 1987-88 studies.

The level of precision obtained in our studies with bulk and individual fascicle/leaf samples of each litter species is expressed for convenience as the minimum shift in each sample mean which would be detected ($\alpha = 0.05$). As in previous annual reports, minimum detectable differences are presented in the summary tables for raw dry matter mass loss data representing each sample type collected on each sampling date in 1989 at each field subunit. Percent nutrient contents for bulk litter samples from the 1987-88 study are also presented with detectable differences. Minimum detectable differences are also reported for treatment means (years, monthly sampling dates, and plantation or hardwood stand subunits) associated with analyses of variance (ANOVA) and selected analyses of covariance (ANACOV), using transformed data. Dry matter mass loss data have been transformed to the arcsin square root of X (where X is the proportion of original mass remaining) to homogenize variances prior to ANOVA or ANACOV. Precision in the raw data sets has generally been highest in the hardwood stand subunits. Among the three study species, pine has provided the most precise data, while maple data are least precise. Dry matter mass loss data are more precise than nutrient data. Our estimates of detectable differences for individual sample dates using raw data are conservative, because ANOVA and ANACOV are much more powerful than are individual sample mean comparisons.

Three-way ANOVA, for detection of differences among years, monthly sampling dates, and plantation or hardwood stand subunits, found that bulk samples of pine and maple litter on both types of subunit decomposed faster in 1985 than in any subsequent year. Bulk oak samples decomposed fastest in 1989, with 1985 in second place. In the hardwood stands, individual pine fascicles and oak leaves also decomposed fastest during 1985 and 1989, respectively. In the plantations, individual pine fascicles and oak leaves decomposed fastest in 1987 and/or 1988.

Oak samples in both hardwood stands and plantations decomposed relatively slowly in 1986. Maple samples decomposed most slowly in 1989. The sampling method for individual fascicles/leaves was improved beginning with the 1986-87 experiment, to involve retrieval of more envelopes containing only one fascicle/leaf per species. As a result, in the exposed environment of the plantations, we are finding that individual oak leaves are decomposing faster than prior to design modification. Significant monthly progress in mass loss during May through October has been the rule in both the plantation and hardwood stand subunits. A variety of significant differences were detected among the hardwood stands and plantations using ANOVA. Many of the statistically detected differences among years, sampling dates, and subunits are attributable to very low variability within the data sets, as indicated by the minimum detectable differences reported. Many of these differences do not appear to be consequential. This issue is discussed in the section of this report entitled Statistical Design. ANOVA did not detect a difference between the hardwood stands either with bulk oak leaves or with individual pine needles. Bulk pine, individual oak leaf, and bulk maple samples decomposed faster in the antenna hardwood stand. ANOVA did not detect any differences among the plantations for individual oak leaves. Individual and bulk pine samples decomposed faster in the ground and control plantations, while bulk oak and bulk maple samples decomposed faster in the ground and antenna plantations.

Covariates have proven to be useful for explaining differences in dry matter mass loss detected by ANOVA among certain critical years. Weather-related covariates were not as helpful with the five-year data set as they were with the four-year data set. This is probably due to our use of covariates to date as independent linear variables. ANACOV has not yet explained the faster decomposition of bulk pine, individual oak leaf or bulk maple samples in the antenna hardwood stand, nor has it explained the faster decomposition of pine samples in the ground and control plantations or of bulk oak and maple samples in the ground and control plantations.

Explanation of all differences in decomposition rate among years for all litter sample types may be an unrealistic goal, especially for the plantations, where vegetational changes are proceeding at different rates and interacting with yearly weather differences. With the exception of individual oak leaves, which decomposed faster in 1988 and 1989 than in earlier years, at least one similarity between a pre-ELF and an ELF year has been identified for each sample type in the plantations and in the hardwood stands.

In the coming year, we will attept to improve the effectiveness of our ANACOV effort by evaluating at least one compolex evapotranspiration-type covariate which integrates measures of precipitation, temperature, and surface soil water-holding capacity. Also, use of the recently completed lignin determinations for the parent littercollections should prove informative.

Nutrient content data for litter samples are now being used solely as covariates to help explain dry matter mass loss. This approach shows great promise in preliminary analysis. The parent litter (initial) nutrient data is biologically independent of ELF effects, because the parent litter collections were made at locations free of ELF fields. The ELF-independence of nutrient content data for samples retrieved from the study sites must yet be shown to allow their use as covariates. Insufficient experience, with nutrient data on hand for only one year each of partial and full ELF exposure, exists to date to confirm ELF-independence or -dependence.

The almost uniformly significant year by site interactions are especially interesting, because they may indicate an ELF effect on decomposition rate. Efforts during the coming year will include determination of when and how often site rankings have shifted. Efforts will also be made to explain these interactions using ANACOV.

Our experimental design is clearly powerful enough to identify very subtle differences in the rates and patterns of bulk and individual fascicle/leaf decomposition, especially in the hardwood stand subunits. Our efforts in 1990 are focusing on 1) collection of the third year's data on litter decomposition in the presence of ELF electromagnetic fields, 2) broader use of covariate analysis to explain additional differences detected by ANOVA among years, monthly sampling dates, and subunits, 3) providing substantial interpretation of year by site interactions, and 4) exploitation of x (periodic decomposition progress) as an alternative dependent variable.

Rhizoplane Streptomycetes

As in previous years, the emphasis of this work element during 1989 was focused on the enumeration and characterization of streptomycetes associated with the predominant mycorrhizal morphology type observed on red pine seedlings planted in 1984 in the three plantations. As a result of miscommunication with new laboratory personnel in the "TREES" project and contamination of a few samples in the Environmental Microbiology laboratory, fewer than the desired six samples per plantation were successfully processed for each sampling date. The problems have been corrected and should not happen again. Pre-weighed washed mycorrhizal fine root subsamples were macerated, serially diluted, and spread-plated onto starch casein agar amended with antifungal antibiotics. After 14 days incubation, counts of streptomycete levels as well as numbers of morphotypes were made. Representatives of each morphotype were subcultured for further characterization, in particular for ability to degrade complex organic compounds. Streptomycete level and morphotype number data were transformed to $\log_{10}$ and subjected to analysis of variance (ANOVA) for detection of differences first within the 1989 sampling season data and then among all years, sampling dates, and plantations. Analysis of covariance (ANACOV) was used to explain differences detected by ANOVA among years, sampling

dates and plantations.

There was no significant difference detected by ANOVA in streptomycete levels among the control, antenna, and ground plantations during the 1989 field season. ANOVA did, however, detect fewer morphotypes at the ground plantation than at the antenna or control plantations. A significant seasonal effect was identified on both levels and morphotype numbers. Streptomycete levels in May were higher than those of August and October, September levels were higher than August, and October levels were lower than all months except August. Morphotype numbers were relatively stable, with May greater than September, and October lower than all other months. This seasonal trend represents a return to the general seasonal trend of significantly greater levels and numbers earlier in the sampling season than in later months, which was observed from 1985 through 1987, but which did not develop in 1988.

When comparing the five annual streptomycete levels and morphotype numbers data sets, significant differences were found among years and months but not among plantations. For levels, the 1987 and 1988 values were significantly higher than those for 1985, 1986, and 1989; the October values were significantly lower than for all other months. Morphotype numbers declined annually from 1985 through 1987, but levelled off in 1988 and 1989. May and June morphotype numbers were greater than those in all other months, while October had fewer morphotypes than any other month. Detectable differences for the $\log^{10}$-transformed five-year data set using ANOVA were less than 1 percent for streptomycete levels and less than 9 percent for morphotype numbers, for years, months, and plantations.

Preliminary ANACOV for streptomycete levels, using air temperature degree days and precipitation frequencies and totals as covariates, explained all differences between years detected by ANOVA, and greatly improved the explanation of plantation differences obtained with ANOVA. A similar ANACOV for morphotype numbers, substituting soil temperature for air temperature, continued the explanation of plantation differences obtained with ANOVA, and also explained several key yearly differences (1986 = 1987, 1986 = 1989, 1987 = 1989). Monthly differences in morphotype numbers were all explained.

In 1989, as in all previous years, the streptomycete morphotype B was commonly isolated at all three plantations on all sampling dates. Other morphotypes frequently detected at all three plantations during the 1989 field season were also routinely detected during previous years. However, the frequency with which morphotype F was recovered declined unexpectedly. Over half of the streptomycetes strains tested, representing all morphotypes detected to date, were able to degrade calcium oxalate, cellulose, and lignocellulose.

Similar, relatively stable streptomycete populations appear to have become established on the red pine seedlings at all three study plantations. During 1990, this work element will focus on 1) obtaining the third year's data on streptomycete levels and morphotype numbers associated with red pine mycorrhiza morphotype

3 in the presence of operational ELF electromagnetic fields, and 2) continuing development of covariate analysis to help explain differences in streptomycete levels and morphotype numbers between years, sampling dates, and plantations.

INTRODUCTION

Forest vegetation dominates the ELF Communications System antenna area. The litter decomposition subsystem of any forest ecosystem serves to 1) pool the nutrients relinquished by primary producers, 2) transform the essential nutrients remaining in litter or trapped by it into forms available for root uptake, and 3) release these nutrients in a regulated fashion for re-use by the autotrophs. The energy provided by litter decomposition also fuels heterotrophic dinitrogen fixation and the capture of nutrients washed from the atmosphere or leached from living plants. As heterotrophic microorganisms, streptomycetes have also been implicated in the calcium and phosphorus nutrition of conifer mycorrhizae, and could influence mycorrhizosphere microbial composition through production of antibiotics, growth factors, etc. Due to the large quantities of potentially available plant nutrients found in the litter component of forest biomass, knowledge of key decomposition processes and their rates is essential to conceptualization of ecosystem dynamics.

Organic matter decomposition is primarily accomplished by microorganisms whose activities are regulated by the environment. Environmental factors which disrupt decomposition processes detract from the orderly flow of nutrients to vegetation. As a new and anthropogenic environmental factor, ELF electromagnetic fields merit investigation for possible effects on the litter decomposition subsystem.

In 1982, Michigan Technological University initiated research at the Michigan antenna site which would determine whether ELF electromagnetic fields cause fundamental changes in forest productivity and health. This research program includes two separate yet highly integrated projects, the Herbaceous Plant Cover and Tree Studies ("Trees") project and the Litter Decomposition and Microflora project. Work elements examining 1) rates of litter decomposition and 2) mycorrhizoplane streptomycete population dynamics were initiated simultaneously with those of the "Trees" project and on the same study units. The two work elements comprising this project complement and extend the baseline studies of the "Trees" project. The information obtained will be used for comparison of pre-operational and operational status of the study variables to evaluate possible ELF electromagnetic field effects on the local forest ecosystem. After seven years, and considerable refinement, we believe that the research studies representing the two work elements of this project are both biologically defensible and statistically rigorous. The overall objectives of these work elements are to determine the impacts of ELF electromagnetic fields on:

1) rates of litter decomposition for three important local tree species (northern red oak, red maple, and red pine), and

2) populations of streptomycete species functionally associated with mycorrhizae of planted red pine seedlings.

Ultimately, the question of whether ELF electromagnetic fields impact these segments of forest communities will be answered by testing various hypotheses (Table 1) based on the results of relatively long-term studies.

Table 1. Critical null hypotheses which will be tested to fulfill objectives of the ELF environmental monitoring program Litter Decomposition and Microflora project.

I.	There is no difference in the level of foliar litter decomposition (dry matter loss) achieved, or the seasonal pattern by which it proceeds, for each study species (northern red oak, red maple, or red pine), that cannot be explained using factors unaffected by ELF antenna operation.
II.	There is no difference in the level or the seasonal pattern of mycorrhizoplane streptomycete populations on the planted red pine seedlings that cannot be explained using factors unaffected by ELF antenna operation.
III.	There is no difference in the representation of different identifiable strains of mycorrhizoplane streptomycetes on the planted red pine seedlings that cannot be explained using factors unaffected by ELF antenna operation.

PROJECT DESIGN

Overview of Experimental Design

Emphasis has been placed from the beginning on development of a statistically rigorous experimental design capable of separating potentially subtle ELF field effects from the natural variability associated with soil, vegetational, climatic and temporal factors. Consequently, in order to most effectively test our hypotheses, we have fully integrated our studies into those of the "Trees" project, permitting us to take full advantage of both that project's basic field design and the extensive data collected by that project on the tree, stand and site factors which influence or regulate the processes and populations we are measuring (Table 2). The measurements made and the associated analyses are discussed more thoroughly in the following sections.

Table 2. Measurements needed to test the critical hypotheses of the ELF environmental monitoring program Litter Decomposition and Microflora project, the objective each group of measurements relates to, and the work elements which address the necessary measurements and analyses.

Hypothesis Number	Related Objective	Measurements	Work Elements
I	1	**Monthly determinations of dry matter loss, from bulk and individual leaf litter samples of oak, maple, and pine**[2]; climatic and biotic variables, soil nutrients, litter nutrient and lignin content	1,(1),(6)[1]
II	2	**Monthly counts of streptomycetes associated with mycorrhizae from planted red pine seedlings**; climatic variables, soil nutrients, mycorrhiza density, seedling growth and moisture stress	1,(2),(4)
III	2	**Monthly determinations of numbers of streptomycete strains associated with Type 3 mycorrhizae from planted red pine seedlings**; climatic variables, soil nutrients, mycorrhiza density, seedling growth and moisture stress	1,(2),(4)

1 Numbers in parentheses refer to work elements in the Herbaceous Plant Cover and Trees project.

2 Bold print designates the response variable; other lists are covariates.

The experimental designs integrate direct measures with site variables, and are a common thread through the work elements of both projects due to shared components of the field design.

Because of the similarity in analyses, an understanding of this experimental design is essential. However, the rationale and progress for measurements in each work element of this study are necessarily unique and will be discussed separately in the following sections.

Field Design

The electromagnetic fields associated with the ELF system will be different at the antenna and ground locations (Anonymous, 1977). As a consequence, forest vegetation at each site could be deferentially affected by both above and below ground fields. Therefore, the general approach of the study required plots to be located along a portion of the antenna, at a ground terminal, and at a control location some distance from the antenna.

The most general experimental design for the "Trees" project is a split-plot in space and time. Each unit (control, antenna, and ground) is subjected to a certain level of ELF field exposure and is subdivided into two stand types (subunits). Pole-sized hardwood stands and red pine (*Pinus resinosa* Ait.) plantations comprise the treatments for this level of the design (Herbaceous Plant Cover and Tree Studies, Annual Report 1986, Figure 1, page 5). Both stand type subunits at each field unit are divided into three contiguous plots to control variation. The time factor is the number of years in which the experiment is conducted for pre-operational and operational comparisons, or the number of sampling periods in one season for year to year comparisons. It is necessary to account for time since successive measurements are made on the same whole units over a long period of time without rerandomization. A combined analysis involving a split-plot in space and time is made to determine both the average treatment response (site difference) over all years, and the consistency of such responses from year to year (Steel and Torrie 1980).

Each unit follows this design with one exception. There is no pole-sized hardwood stand subunit at the ground unit because the necessary buffer strips would have resulted in the hardwood subunit being too distant from the grounded antenna for meaningful exposure. Thus one treatment factor (hardwood stands) is eliminated at the ground unit. Depending on the variable of interest, the stand type treatment factor may or may not be pertinent. Where analyses are conducted on only one stand type, the stand type treatment factor is irrelevant and is not included in the analysis. This is the case for all studies of the Litter Decomposition and Microflora project. All other factors remain unchanged.

Statistical Design

Analysis of variance (ANOVA) and analysis of covariance (ANACOV) are used in our studies to determine effects of treatments (year, individual plantation or hardwood stand, monthly sampling date, and Elf field exposure) on decomposition progress and streptomycete population levels. The statistical design employed in both study elements reported here is a factorial design with blocking and covariates. The factors included in the design vary somewhat by experiment, but include year, month, unit, and blocking. Recall that unit represents the three ELF treatments, control, ground, and antenna. Separate analyses are conducted for the hardwood stand and pine plantation subunits to satisfy the assumptions required by the analysis of variance and analysis of covariance models. These experiments are not split-plot experiments across time, a design frequently used in the "Trees" project, because the experimental units are destructively sampled to obtain the required measurements. A split-plot design across time requires repeated measurements on the same experimental unit.

Blocking is employed to control variability in all experiments, but the definition of blocks varies between experiments. The unit of blocking in the streptomycete experiments is the plantation subunit, with 6 replicates per block. The unit of blocking for the bulk leaf litter experiments is the plot (3 plots per subunit), with 2 replicates per block. For the individual leaf samples, the location of each group of leaf bags (24 groups per subunit) is a block, from which one replicate bag is removed each month. The blocking employed produces a balanced incomplete block design (i.e., not all ELF treatments can be represented in each block). This design is dictated by the spatial separation of the ELF treatments.

Our experimental design directly controls experimental error to increase precision. Indirect or statistical control can also reduce variability and remove potential sources of bias through the use of covariate analysis. This involves the use of variables (covariates) which are related to the variable of interest (variate). Covariate analysis removes the effects of an environmental source of variation that would either inflate the experimental error or inappropriately increase the variability explained by the treatments. Identification of covariates which are both biologically meaningful and independent of treatment effects is one of the most important steps in our current analysis. Covariates will have to be shown to be unaffected (both directly and indirectly) by ELF fields before they can be legitimately used to explain (with respect to ELF fields) any differences in response variables between years or units. The independence of the ambient conditions covariates will be tested by the "Trees" project.

Covariates under examination differ among the dependent variables considered (Table 2). Most analyses use climatic variables computed from weather data, such as monthly mean air temperature, monthly mean soil temperature, monthly total

precipitation and the number of precipitation events each month. Depending on the variable of interest, microsite factors will also be considered. Other factors considered are more specific to the observation; for example, other covariates in the analysis of mycorrhizoplane streptomycete populations could include seedling diameter, seedling height, current season seedling shoot length, simultaneous Type 3 mycorrhiza density, and plant moisture stress. Analyses will be conducted to determine which of these are both biologically meaningful and statistically significant without violating the necessary assumptions required for the analysis of covariance (Cochran, 1957).

The treatment means presented for each ANOVA and the adjusted treatment means for each ANACOV model employ either the arc sin square root transformation of raw data (litter decomposition, as dry matter mass loss) or the $\log_{10}$ transformation (streptomycete levels and types). The adjusted treatment means are adjusted for the covariate(s) used, and represent the transformed data after the treatment means have been adjusted for the effect of the covariate(s). Throughout the ANACOV discussion, differences detected between means are <u>after</u> the effect of the covariate(s) has been considered. Thus, for example, when it is stated that decomposition failed to progress during a given month, the interpretation should be that the covariate(s) adequately explained any change that may have occurred during that month.

As noted above, the experimental design appropriately supports statistical data analysis by three-way ANOVA and ANACOV. Nevertheless, the sample means presented in figures throughout this report are accompanied by bars indicating the bounds of 95 percent confidence intervals. These confidence intervals are provided as a means of depicting relative sample variability, and do not represent the multiple (or pairwise) comparisons associated with ANOVA or ANACOV, respectively. The error bars in the figures are based on small samples, the number of observations for each specific treatment combination. ANOVA and ANACOV are based on much larger samples, and tend to explain much more variability - partly because n is larger, but also because factors used for statistical blocking and covariance analysis, which contribute to error when calculating the confidence intervals, are included in the ANOVA model. The error bars on the figures are therefore quite conservative when compared to ANOVA results. In other words, a significant difference may be found by ANOVA or ANACOV even if all confidence intervals overlap, if a consistent and sufficient trend exists between at least two levels of a given factor (i.e., monthly sampling dates, years, or different hardwood stand or plantation subunits). We discussed an example of ANOVAs ability to detect a systematic trend in last year's report (<u>Annual Report 1987</u>, page 16).

As sample size increases and/or sample variance decreases, detection of a statistically significant difference between treatments becomes increasingly likely. Yet the biological effect of the given treatments on the dependent variable remains unchanged, and is either consequential (biologically significant)

or not, regardless of the statistical significance achieved. According to Mize and Schultz (1985),

> "Means can be consequentially and (or) statistically different. A consequential difference is a difference that is large enough to be important. A statistical difference is a difference that is larger than expected, given the variability of the characteristic that was studied. Sometimes, consequential differences are not statistically different. Also, statistical differences are sometimes not consequential. The researcher should be primarily interested in discussing the statistical significance of consequential differences."

Our experimental design with respect to litter decomposition is powerful enough to detect some statistical differences which, because of their small size, appear to be inconsequential. We view this situation to be highly preferable to the reverse situation. Nevertheless, we expect that careful use of ANACOV will explain additional differences (e.g., between certain years) detected by ANOVA.

Alternative Dependent Variables to Measure Litter Decomposition

The dependent variable used in this study to measure dry matter mass loss has been the proportion of initial dry matter mass remaining when the samples are retrieved from the study sites. This value is represented in the following discussion by x_i, where i represents the month of sample retrieval. An alternative response variable, suggested by one of the peer reviewers, is the rate of change in dry matter mass between sampling dates. This value will be represented in the following discussion by x_i. The purpose of this section is to discuss the relative merit of using x_i as the dependent variable, and to request references and insights from the peer reviewers concerning the choice of dependent variable.

The possible advantages of using x_i to model decomposition are:

1) to circumvent concern about the lack of independence between observations of mass remaining at different points in time during the sampling year (suggested by reviewer),
2) elapsed time between sample collection dates could be explicitly included in the analysis of litter decomposition (suggested by reviewer), and
3) explanation of differences between sites and years using covariates may be facilitated.

The possible disadvantages of using x_i to model decomposition are:

1) actual loss of statistical power caused by variance inflation which occurs when two random variables are subtracted (or added),

2) perceived loss of statistical power resulting from comparing small magnitude responses (x_i) versus large magnitude responses (x_i), and
3) the fact that the errors associated with x_i will no longer be independent.

Each of these issues is discussed below.

Advantage 1: Concern about Lack of Independence

The major argument, as stated by the peer reviewer, against using x_i as the response variable is that the mass remaining in one month is not independent of the mass remaining in other months. The reviewer is concerned that this violates the assumptions of ANOVA. Actually, ANOVA requires that the errors associated with the response variables be independent. The argument can briefly be summarized algebraically as follows:

Define $x_1 = x_0 - x_1$, or, in general, $x_i = x_{i-1} - x_i$. Then, the proportion of dry matter mass remaining at any point in time can be expressed as:

$$x_j = x_0 - \sum_{i=1}^{j} x_i. \qquad (1)$$

From this equation, it is clear that x_j is the sum of x_0 (which is known with certainty) and j random variables (the x_i).

Thus, the error term associated with x_j is a function of the error terms of the j x_i. Furthermore, the next month's response (x_{j+1}) can be expressed as:

$$x_{j+1} = x_0 - \sum_{i=1}^{j+1} x_i. \qquad (2)$$

Since the first j terms of the sum on the right side of this equation are identical to the sum of Equation 1, the errors of these two variables are clearly related.

However, it is not clear that this argument can be applied to the experimental design of this study. The argument assumes that Equations 1 and 2 represent subsequent measurements on the same sample (experimental unit). Each sample in this study is retrieved and measured only once (i.e., destructive sampling is employed). Thus, the two measurements (x_j and x_{j+1}) represented by Equations 1 and 2 actually represent different samples. Because of randomization, the errors associated with these two measurements are independent. For this reason, we believe that the current choice of independent variable does not violate the independence assumption required by ANOVA.

Advantage 2: Incorporation of Elapsed Time

As noted by one of the technical reviewers, elapsed time of exposure in the field is not currently addressed explicitly in

the modelling effort. Rather, it is implicitly included in the categorical variable (treatment) "month". However, the collection date varies, usually slightly, from month to month, and from year to year.

This information could easily be included in the analysis if x_i (rather than x_i) were chosen as the dependent variable. This could be done by defining the response variable as the rate of change:

$$Y_i = x_i/t,$$

where t is the number of days between sample collection for month i-1 and i.

Advantage 3: Enhanced Covariate Analysis

Much of the previous and current modelling effort for this project has focused on use of covariance analysis to explain site and year differences detected by ANOVA. Although this approach has produced encouraging results, many differences have not been explained. One explanation of the limited success of covariates is that any specific set of values representing cumulative seasonal weather variables, (measuring, for example, temperature and moisture) does not reflect a unique set of conditions for decomposition progress. There are many ways that a specific set of cumulative temperature and moisture measures can result, and these different weather sequences can present markedly different conditions for decomposition progress. For example, consider a year with a cold, wet spring followed by a hot, dry summer. This sequence could lead to cumulative temperature and moisture data which are near average. However, neither the cold, wet spring nor the hot, dry summer would be especially conducive to rapid decomposition. It seems likely that, by using weather information representing shorter periods of time (e.g., the monthly period representing x_i), this information would more closely capture the environment in which decomposition is proceding. Weather information prior to the most recent month would likely still be helpful, as a measure of the inertia developed by the decomposer community prior to the most recent month. We are also evaluating the usefulness of variables related to AET (actual evapotranspiration), which would integrate the effects of moisture and temperature.

Disadvantage 1: Loss of Statistical Power from Variance Inflation

x_i was defined above as:

$$x_i = x_{i-1} - x_i.$$

Recall that it was argued above (under the heading "Advantages: Concern about Lack of Independence") that the errors associated with x_{i-1} and x_i are independent random

variables. Furthermore, the errors associated with the random variables are assumed to be normally distributed (this is a required assumption of ANOVA). The difference between two independent normally distributed random variables (x_{i-1} with mean μ_{i-1} and variance σ_{i-1}^2 and x_i with mean μ_i and variance σ_i^2) is distributed as a normal random variable with mean equal to the difference between the two means ($\mu_{i-1} - \mu_i$) and variance equal to the sum of the variances ($\sigma_{i-1}^2 + \sigma_i^2$). Therefore, the resulting random variable (x_i) will be more variable than either of the original random variables. If we assume that $\sigma_{i-1}^2 = \sigma_i^2$, then the magnitude of the increase in the standard deviation will be about 40% (s.d. $x_i = (\sigma^2 + \sigma^2)^{0.5} = 2^{0.5}\sigma$).

Disadvantage 2: Perceived Loss of Statistical Power

It is often the case that the power of statistical analyses is summarized by stating the proportional change in the dependent variable that could be detected with specified probability. x_i will be much smaller than x_i. Therefore, a perception that the statistical tests are much less powerful when x_i rather than x_i is used as the dependent variable may occur. This perceived reduction in power will be a remnant of the analysis technique used to summarize power. Except for the variance inflation discussed above, the power of the analysis to detect treatment differences (site, year, and site-year interaction) will remain unchanged.

Disadvantage 3: Loss of Independence of Errors

Recall that x_i is the difference between x_i and x_{i-1}, and that the errors associated with x_i and x_{i-1} are independent normal random variables. Consider two sequential measurements of x_i:

$$x_i = x_{i-1} - x_i, \text{ and}$$
$$x_{i+1} = x_i - x_{i+1}.$$

From these equations, it is clear that both x_i and x_{i+1} are functions of x_i. Therefore, the error term associated with x_i is included in both x_i and x_{i+1}, and it follows that the error terms of x_i and x_{i+1} are not independent. This violates the assumption required for ANOVA and ANACOV that the error terms be independent. ANOVA and ANACOV are often quite robust when this assumption is violated, and the degree of dependence is restricted to adjacent measurements in time. Also, the large sample sizes will tend to dilute the impact of this ANOVA/ANACOV assumption violation.

Future Plan of Action

We are currently in the process of data manipulation to generate a suitable dataset, which will be used to prototype and test use of x_i as a dependent variable. Results of this effort may be available for the final draft of this report.

We would appreciate any comments, insights, references, or

criticisms that the peer reviewers could provide concerning this issue.

WORK ELEMENTS

The work elements of the Litter Decomposition and Microflora project acknowledge the two diverse study areas included within this project. Data from several work elements of the "Trees" project are used to test each hypothesis posed by this project (Table 2). The following sections present a synopsis of the rationale for study, measures, and analyses conducted in each work element of this project.

ELEMENT 1: LITTER DECOMPOSITION AND NUTRIENT FLUX

Introduction

Litter decomposition comprises a complex of processes involving a variety of organisms engaged in the degradation of a wide range of organic substrates. Loss of dry matter mass over time from freshly fallen foliar litter samples has traditionally been used as a measure of fully integrated litter decomposition (Kendrick 1959, Jensen 1974, Millar 1974, Witkamp and Ausmus 1976). Both the accuracy and precision of dry matter mass loss as a sensitive index of organic matter deterioration, however, decline with time beyond approximately one year, depending on the ecosystem (Fogel and Cromack 1978). We are also finding that mass loss characterization on the basis of individual leaves provides additional biologically meaningful information about the decomposition process and the rates at which it naturally proceeds for different litter species, beyond that provided by study of mass loss for bulk samples. Bulk sample estimates of mass loss rates actually represent running averages of the decomposition rates (including fragmentation) operating in the individual leaves comprising the bulk sample. These average rates are nevertheless essential for conversion of nutrient concentrations determined for bulk litter samples from percent values to masses for calculation of nutrient flux. The increased sample sizes accompanying individual leaf studies also permit more accurate establishment of decomposition rates for comparison between subunits, years, and monthly sampling dates.

Microfloral population shifts have been shown to influence the rate of total litter decomposition (Mitchell and Millar 1978). Conversely, dry matter mass loss and nutrient flux are useful measures of the impact of environmental perturbations on the integrated activities of the litter biota. The methods employed in these studies integrate the activities of all but the largest soil fauna, and ELF fields represent one possible cause of environmental perturbation.

Studies of litter decomposition and associated nutrient flux extend the usefulness of litter production data collected in the course of forest vegetation studies. Knowledge of litter biomass production and nutrient content conversely provide one link between the overstory and forest floor components of the forest ecosystem.

The forest vegetation at all three study sites is classified in the Acer-Quercus-Vaccinium habitat type (Coffman et al. 1983). The two hardwood species selected for study, northern red oak (Quercus rubra) and red maple (Acer rubrum), are common to both of the hardwood stand subunits. The conifer species selected for study (Pinus resinosa) exists as scattered mature specimens throughout the area. These three study species represent a range of decomposition strategies and rates. Red pine was also selected because the influence of fragmentation can be eliminated through experiments with individual fascicles.

A fifth year's experience with red pine, northern red oak,

and red maple foliar litter decomposition and nutrient flux has been gained on the antenna, ground, and control units. The 1988-89 study represented the sixth year of experience with red pine on the antenna and ground units. Experience to date supports the contention that mass loss and nutrient flux over time from freshly fallen foliar litter can be characterized with sufficient precision to detect subtle environmental perturbations.

Methods

Litter decomposition is being quantified as percent change over time in dry matter mass. Experiments are conducted annually and focus on the first year following each year's autumn litterfall.

A single parent litter collection, from a single location, is made for each study species in order to avoid the effects of possible differences in substrate quality associated with geographically different litter sources. Ratios of fresh to dry matter mass and initial nutrient content are determined for approximately 15 random samples taken at regular intervals during field sample preparation from each of the annual pine, oak, and maple litter parent collections. Analysis of litter nutrient content is being conducted by the Soils Analysis Laboratory, School of Forestry and Wood Products, Michigan Technological University. Laboratory protocol includes analysis of NBS standard no. 1575 (pine needles), as every 20th sample for N and P, and as every 15th sample for cations. All mass loss data (dry matter as well as nutrient masses) are based on 30°C dry masses. Samples destined for the field are pre-weighed and enclosed in nylon mesh envelopes (3 mm openings) constructed to lay flat on the ground.

All samples are disbursed in the field during early December, and subsets are retrieved at approximately monthly intervals from early May to early December. Snow cover at the study sites dictates early May to be the earliest possible recovery date, because samples are frozen to the ground until snowmelt is complete. Likewise, snow cover dictates early November as the latest possible recovery date from the plantation subunits, because samples are frozen to the ground by the early December sampling date. Early December collections are possible in the hardwood stand subunits, where sample envelopes are less severely weathered by early December, and are still relatively easy to separate from the surrounding litter.

Raw data are expressed as the proportion (X) of original dry matter mass remaining over time. Dry matter mass loss is being studied by an individual fascicle/leaf method as well as via bulk litter samples. Nutrient flux is determined solely for the bulk litter samples. Individual fascicles/leaves offer the opportunity to study decomposition of basic foliage units. Each individual fascicle or leaf is completely intact at the time of disbursal. The influence of fragmentation on individual pine fascicle decomposition is especially easy to eliminate by

discarding any fascicles broken during the course of study.

Sufficient samples were recovered each month to permit analysis of differences in dry matter losses between subunits, years, and monthly sampling dates by ANOVA and ANACOV. Dry matter mass loss data are transformed to the arc sin square root of X, to homogenize variances prior to correlation analysis, ANOVA, and ANACOV (Steel and Torrie 1980). The arc sin square root transformation is recommended for use with data expressed as decimal proportions less than 1.00, especially when proportions within a data set vary widely.

In all statistical analyses performed, acceptance or rejection of the null hypothesis is based on $\alpha = 0.05$, regardless of the statistical test employed. Differences which are significant ($p \leq 0.05$) are presented along with the attained significance level (p) of the test statistic. Multiple range comparisons among significant differences detected by ANOVA and ANACOV are being identified by the least square means pairwise comparison procedure (SAS Institute, Inc. 1985). All ANOVAs and ANACOVs presented here have been conducted on the mainframe computer at MTU, using PROC CORR or PROC GLM of the Statistical Analysis System (SAS Institute, Inc. 1985).

Sufficient decomposition and weather data are available for a substantial modeling effort. Several weather and biotic variables have been evaluated as covariates to date. Our use of ANACOV to explain differences detected by ANOVA has been introduced under Project Design (pages 12 - 15). Covariates to be evaluated in the coming year include initial lignin and nutrient content, nutrient content of retrieved samples, soil and vegetative cover variables, litterfall characteristics, and additional weather variables (both integrated and periodic in nature). Our success so far with weather-related variables probably underestimates their importance biologically, because they have been calculated independently of one another. For this reason, we are working on construction of covariates similar to actual evapotranspiration (AET: e.g., Thornthwaite and Mather 1957, Meentemeyer and Berg 1986), which will integrate temperature, precipitation, water-holding capacity, and lattitude. As a guiding principle, only variables which can be shown to be unaffected by ELF electromagnetic fields to date will be considered as potentially useful covariates, since ANOVA and ANACOV are proposed as our principle tools for detection of any ELF-induced shift(s) of litter decomposition rates.

Throughout the study, all bulk litter samples have been ground for nutrient analysis. The residual portion of every ground sample, beyond the portion required for analysis of N, P, K, Ca, and Mg contents, has been archived for future reference. As time and resources permit, the lignin and carbon contents of selected samples may be determined, for use as covariates. The residual portions of the autumn, 1988, parent litter collections have also been archived to permit establishment of a future decomposition experiment, which will compare the decomposition of samples derived from litter collected during different years. This experiment will afford an opportunity to determine whether

or not source litter quality variables could be responsible for any unexplained differences which remain among our annual experiments.

Initial lignin content of the 15 parent litter collections (3 spp., 5 yr) will soon be available for evaluation as a covariate. Lignin content is being estimated using the technique described by TAPPI (Official Testing Method T 222 om-88, revised 1988), entitled "Acid-insoluble lignin in wood and pulp". The only modification to this procedure involves autoclaving the digesting sample for 1 hour rather than boiling it for 4 hours (step 9.4; V.L.C. Chiang, personal communication). Other studies have found lignin content useful for explaining differences in decomposition rate (e.g., Melillo et al. 1982). We anticipate that lignin content may be most useful in evaluating the maple data, as the influence of lignin on decomposition rate increases as weight loss progresses (Meentemeyer and Berg 1986, Berg et al. 1984, Fogel and Cromack, Jr. 1977).

Our approach to studying the nutritional aspects of litter decomposition has shifted, from the original intent to consider nutrient fluxes as dependent variables, toward use of percent nutrient contents as covariates to help explain dry matter mass loss. In light of this shift of emphasis, we have cautiously reduced the intensity of nutrient analysis conducted on samples retrieved from the field. We will continue to fully analyze the bulk standard samples representing the parent litter collections. We will also continue to archive all bulk samples retrieved from the field. However, we will conduct nutrient analysis only on samples retrieved during alternate months, representing May, July, September, and November. A graduate student or technician will be hired with the resources made available by this shift of emphasis, whose responsibilities will be to facilitate further analysis as well as publication of data and results accumulated by this study.

1988-89 Study

Fresh-fallen red pine litter was again collected on polyethylene tarps (provided with drainage) spread in the LaCroix red pine plantation near Houghton, due to 1) its proximity to MTU, and 2) its remoteness from interfering ELF (76 Hz) electromagnetic fields. Fresh-fallen red maple litter was again collected near the Covered Drive, seven miles from Houghton, for the same reasons. Northern red oak litter was again collected near the northeast edge of the control plantation subunit plot 3.

Bulk pine sample envelopes measured 22 cm x 28 cm; each contained 10 g (air dry mass) of the parent collection. Bulk maple and oak sample envelopes measured 44 cm x 28 cm; each contained 15 g (air dry mass) of the parent collection. For the 1988-89 study, individual leaf envelopes measured 22 cm x 28 cm, and each contained one pine fascicle and one oak leaf.

Prior to the 1986-87 study, individual leaf envelopes contained multiple tethered leaves of a single species, and one envelope per month per species was recovered from each plantation

or hardwood stand subunit plot. Beginning with the 1987 field season, we collected 1 envelope (containing one pine fascicle and one oak leaf) from each of 8 locations per plot each month. Two advantages to this modified method were forseen:

1. The individual study leaves of each species are more clearly independent of one another.

2. Recovery of individual leaf envelopes from 24 locations per subunit (instead of 3) better represents site variability.

It appears that this adjustment in experimental design for the study of individual leaf decomposition may prevent comparison of individual oak leaf data collected in the plantations in different years by the two methods. Regardless, the ability to compare antenna and ground subunits with the corresponding subunits at the control site will be enhanced by the improvement in experimental design.

It should be emphasized that the experimental design regarding bulk litter envelopes remains unaltered. Ten bulk litter envelopes of each species were placed together at two locations on each of the three plots comprising each subunit. One bulk envelope per species was retrieved each month from each of these 6 locations per subunit.

1989-90 Study

Fresh-fallen red pine, northern red oak, and red maple foliar litter were collected again in 1989 as described for the 1988-89 study. The same experimental design established for the 1984-85 through 1988-89 studies is being followed for bulk litter samples in the 1989-90 study. The same experimental design for individual fascicle/leaf study established with the 1986-87 study is being continued with the 1989-90 study, with the single exception that only pine fascicles and oak leaves are included.

Description of Progress

1988-89 Study

Tables 3 and 4 present mean dry matter mass loss summaries (raw, untransformed data) for the bulk and individual fascicle pine samples retrieved in 1989 (by sampling date and subunit), along with standard deviations and minimum detectable differences (based on 95 percent confidence intervals for sample means). Tables 5 and 6 present the corresponding data from all five study subunits for bulk and individual oak leaf samples. Corresponding data for bulk maple samples are presented in Table 7. The data show that the following shifts in bulk and individual fascicle/leaf sample means should be detectable (α = 0.05).

Table 3. Mean proportion[a] of initial dry matter mass (30°C) remaining at different times in 1989, for bulk red pine foliar litter samples disbursed in early December, 1988.

Sampling Date	Antenna Unit					
	Plantation			Hardwood Stand		
	Mean[a]	S.D.[b]	%[c]	Mean	S.D.	%
11 May	0.91	0.01	2	0.90	0.01	1
10 June	0.89	0.02	3	0.89	0.02	2
8 July	0.86	0.03	3	0.86	0.01	2
5 August	0.84	0.02	2	0.83	0.01	1
9 September	0.78	0.02	3	0.78	0.00	1
9 October	0.76	0.02	2	0.74	0.01	1
13 November	0.76	0.02	3	0.74	0.02	2
9 December						

Table 3. (cont)

Sampling Date	Control Unit					
	Plantation			Hardwood Stand		
	Mean	S.D.	%	Mean	S.D.	%
11 May	0.91	0.02	2	0.92	0.02	2
10 June	0.88	0.02	2	0.89	0.02	3
8 July	0.85	0.01	1	0.87	0.02	3
5 August	0.81	0.03	3	0.83	0.02	3
9 September	0.79	0.01	2	0.81	0.01	2
9 October	0.73	0.01	2	0.78	0.02	2
13 November	0.76	0.04	6	0.77	0.01	1
9 December						

Table 3. (cont)

Sampling Date	Ground Unit		
	Plantation		
	Mean	S.D.	%
11 May	0.90	0.02	2
10 June	0.87	0.02	2
8 July	0.85	0.02	2
5 August	0.81	0.03	3
9 September	0.78	0.02	3
9 October	0.73	0.04	5
13 November	0.75	0.02	3
9 December			

a/ Proportion ($X = M_1/M_0$), where M_0 and M_1 represent the 30°C dry matter masses of samples initially and at time 1, respectively. Dry matter mass at time 0 was estimated from fresh to dry mass (30°C) ratios determined for separate random subsamples taken at the time of litter sample preparation. These samples were also used to determine initial nutrient content.

b/ standard deviation

c/ detectable difference: estimated shift in each mean value which would be detected 95 percent of the time (α = .05), calculated as $t_{0.05,5}$ * S.E./Mean, and expressed as a percentage of the sample mean

Table 4. Mean proportion[a] of initial dry matter mass (30°C) remaining at different times in 1989, for individual red pine fascicles disbursed in early December, 1988.

Sampling Date	Antenna Unit					
	Plantation			Hardwood Stand		
	Mean[a]	S.D.[b]	%[c]	Mean	S.D.	%
11 May	0.94	0.02	1	0.94	0.02	1
10 June	0.91	0.02	1	0.91	0.02	1
8 July	0.86	0.03	2	0.88	0.03	1
5 August	0.84	0.03	2	0.85	0.04	2
9 September	0.78	0.04	3	0.79	0.03	2
9 October	0.78	0.05	3	0.78	0.04	2
13 November	0.75	0.04	3	0.78	0.04	2
9 December				0.76	0.03	2

Table 4. (cont)

Sampling Date	Control Unit					
	Plantation			Hardwood Stand		
	Mean	S.D.	%	Mean	S.D.	%
11 May	0.93	0.02	1	0.96	0.02	1
10 June	0.91	0.02	1	0.93	0.02	1
8 July	0.87	0.03	2	0.90	0.03	1
5 August	0.82	0.03	2	0.87	0.02	1
9 September	0.77	0.03	2	0.83	0.04	2
9 October	0.79	0.04	3	0.81	0.03	2
13 November	0.77	0.05	3	0.81	0.03	2
9 December				0.79	0.03	2

Table 4. (cont)

Sampling Date	Ground Unit		
	Plantation		
	Mean	S.D.	%
11 May	0.93	0.02	1
10 June	0.91	0.02	1
8 July	0.87	0.03	1
5 August	0.83	0.03	2
9 September	0.76	0.03	2
9 October	0.76	0.05	3
13 November	0.75	0.04	3
9 December			

a/ Proportion ($X={}^{M_1}/M_0$), where M_0 and M_1 represent the 30°C dry matter masses of samples initially and at time 1, respectively. Dry mass at time 0 was estimated from fresh to dry mass (30°C) ratios determined for separate random subsamples taken at the time of litter sample preparation.

b/ standard deviation

c/ detectable difference: the estimated shift in each mean value which would be detected 95 percent of the time (α = .05), calculated as $t_{.05,n}$ * S.E./Mean, and expressed as a percentage of the sample mean (n = 30, or less depending on fragmentation)

Table 5. Mean proportion[a] of initial dry matter mass (30°C) remaining at different times in 1989, for bulk northern red oak foliar litter samples disbursed in early December, 1988.

Sampling Date	Antenna Unit					
	Plantation			Hardwood Stand		
	Mean[a]	S.D.[b]	%[c]	Mean	S.D.	%
11 May	0.92	0.04	4	0.93	0.01	1
10 June	0.89	0.02	3	0.89	0.03	4
8 July	0.85	0.02	2	0.84	0.03	3
5 August	0.80	0.07	9	0.79	0.03	3
9 September	0.73	0.05	7	0.73	0.02	3
9 October	0.72	0.05	7	0.71	0.04	7
13 November	0.69	0.05	8	0.68	0.03	4
9 December						

Table 5. (cont)

Sampling Date	Control Unit					
	Plantation			Hardwood Stand		
	Mean	S.D.	%	Mean	S.D.	%
11 May	0.92	0.02	2	0.92	0.02	2
10 June	0.88	0.01	1	0.90	0.03	3
8 July	0.84	0.02	2	0.86	0.03	4
5 August	0.81	0.02	2	0.82	0.03	4
9 September	0.75	0.02	2	0.78	0.03	4
9 October	0.70	0.02	2	0.75	0.03	4
13 November	0.68	0.04	7	0.73	0.04	5
9 December						

Table 5. (cont)

Sampling Date	Ground Unit		
	Plantation		
	Mean	S.D.	%
11 May	0.91	0.04	5
10 June	0.86	0.03	3
8 July	0.83	0.02	3
5 August	0.77	0.03	4
9 September	0.73	0.03	5
9 October	0.70	0.03	5
13 November	0.67	0.05	7
9 December			

a/ Proportion ($X = M_1/M_0$), where M_0 and M_1 represent the 30°C dry matter masses of samples initially and at time 1, respectively. Dry matter mass at time 0 was estimated from fresh to dry mass (30°C) ratios determined for separate random subsamples taken at the time of litter sample preparation. These samples were also used to determine initial nutrient content.

b/ standard deviation

c/ detectable difference: the estimated shift in each mean value which would be detected 95 percent of the time (α = .05), calculated as $t_{.05,5}$ * S.E./Mean, and expressed as a percentage of the sample mean.

Table 6. Mean proportion[a] of initial dry matter mass (30°C) remaining at different times in 1989, for individual northern red oak leaves disbursed in early December, 1988.

Sampling Date	Antenna Unit					
	Plantation			Hardwood Stand		
	Mean[a]	S.D.[b]	%[c]	Mean	S.D.	%
11 May	0.92	0.04	2	0.92	0.03	1
10 June	0.80	0.06	3	0.88	0.05	3
8 July	0.74	0.08	4	0.83	0.05	2
5 August	0.70	0.09	5	0.78	0.06	3
9 September	0.65	0.09	6	0.68	0.05	3
9 October	0.60	0.09	6	0.68	0.05	3
13 November	0.55	0.09	7	0.63	0.07	5
9 December				0.60	0.10	7

Table 6. (cont)

Sampling Date	Control Unit					
	Plantation			Hardwood Stand		
	Mean	S.D.	%	Mean	S.D.	%
11 May	0.90	0.04	2	0.94	0.03	2
10 June	0.83	0.06	3	0.89	0.05	2
8 July	0.75	0.09	5	0.86	0.05	2
5 August	0.66	0.12	7	0.81	0.06	3
9 September	0.65	0.08	5	0.75	0.05	3
9 October	0.61	0.08	5	0.76	0.05	3
13 November	0.56	0.08	6	0.69	0.08	5
9 December				0.70	0.09	6

Table 6. (cont)

Sampling Date	Ground Unit		
	Plantation		
	Mean	S.D.	%
11 May	0.90	0.05	2
10 June	0.79	0.06	3
8 July	0.74	0.07	4
5 August	0.67	0.09	6
9 September	0.59	0.06	5
9 October	0.62	0.08	6
13 November	0.55	0.07	6
9 December			

a/ Proportion ($X = M_1/M_0$), where M_0 and M_1 represent the 30°C dry matter masses of samples initially and at time 1, respectively. Dry matter mass at time 0 was estimated from fresh to dry mass (30°C) ratios determined for separate random subsamples taken at the time of litter sample preparation.

b/ standard deviation

c/ detectable difference: estimated shift in each mean value which would be detected 95 percent of the time (α = .05), calculated as $t_{.05,29}$ * S.E./Mean, and expressed as a percentage of the sample mean

Table 7. Mean proportion[a] of initial dry matter mass (30°C) remaining at different times in 1989, for bulk red maple foliar litter samples disbursed in early December, 1988.

Sampling Date	Antenna Unit					
	Plantation			Hardwood Stand		
	Mean[a]	S.D.[b]	%[c]	Mean	S.D.	%
11 May	0.92	0.03	3	0.92	0.02	2
10 June	0.85	0.02	3	0.87	0.01	1
8 July	0.83	0.02	2	0.87	0.03	3
5 August	0.77	0.02	3	0.82	0.02	2
9 September	0.76	0.04	6	0.77	0.04	6
9 October	0.70	0.04	5	0.73	0.02	3
13 November	0.68	0.08	12	0.77	0.02	3
9 December						

Table 7. (cont)

Sampling Date	Control Unit					
	Plantation			Hardwood Stand		
	Mean	S.D.	%	Mean	S.D.	%
11 May	0.91	0.03	3	0.92	0.03	3
10 June	0.86	0.03	4	0.90	0.02	3
8 July	0.83	0.02	2	0.88	0.02	2
5 August	0.81	0.02	3	0.87	0.02	3
9 September	0.73	0.04	6	0.81	0.02	2
9 October	0.72	0.03	4	0.80	0.03	4
13 November	0.72	0.03	5	0.80	0.02	3
9 December						

Table 7. (cont)

Sampling Date	Ground Unit		
	Plantation		
	Mean	S.D.	%
11 May	0.89	0.01	1
10 June	0.85	0.01	2
8 July	0.80	0.03	5
5 August	0.77	0.02	3
9 September	0.73	0.04	6
9 October	0.67	0.03	5
13 November	0.71	0.03	4
9 December			

a/ Proportion ($X = M_1/M_0$), where M_0 and M_1 represent the 30°C dry matter masses of samples initially and at time 1, respectively. Dry matter mass at time 0 was estimated from fresh to dry mass (30°C) ratios determined for separate random subsamples taken at the time of litter sample preparation. These samples were also used to determine initial nutrient content.

b/ standard deviation

c/ detectable difference: estimated shift in each mean value which would be detected 95 percent of the time (α = .05), calculated as $t_{.05,5}$ * S.E./Mean, and expressed as a percentage of the sample mean

A. Pine
   1. Plantation Subunits
      a. Individual Fascicles - 3%
      b. Bulk Samples - 6%
   2. Hardwood Stand Subunits
      a. Individual Fascicles - 2%
      b. Bulk Samples - 3%
B. Oak
   1. Plantation Subunits
      a. Individual Fascicles - 7%
      b. Bulk Samples - 9%
   2. Hardwood Stand Subunits
      a. Individual Fascicles - 7%
      b. Bulk Samples - 7%
C. Maple
   1. Plantation Subunits
      a. Bulk Samples - 12%
   2. Hardwood Stand Subunits
      a. Bulk Samples - 6%

Results of ANOVA and ANACOV

For this year's report, litter decomposition ANOVA and ANACOV models for each litter sample type and species, on both the plantation and hardwood stand subunits, were evaluated both with and without year by site interactions. Both types of model are presented for comparison throughout the report. The ANOVA or ANACOV table will always precede the table of means and comparisons for that model (e.g., Tables 8 and 9), and the model without the year by site interaction will always precede the model with the interaction specified (e.g., Tables 8 - 11). A significant year by site interaction indicates that the pattern of significant differences among years depends on the site. When a significant year by site interaction is identified for a model, the effects of year and site can not be evaluated independently. Future reports will use separate analyses for individual years where significant year by site interactions can not be explained by ANACOV.

ANOVA Results - Individual Fascicle/Leaf Samples

Individual Pine Fascicles

Table 8 presents the 3-way ANOVA table for detection of significant differences in dry matter mass loss among years, monthly sampling dates, and plantations. Monthly samples were collected near the beginning of the months indicated for multiple comparisons. Table 9 presents 1) means and standard errors for the treatments (years, months, plantations), 2) detectable differences for each treatment based on 95 percent confidence intervals, and 3) significant differences detected by ANOVA and identified by SAS Proc GLM's Least Square Means procedure (SAS Institute Inc. 1985). Tables 10 and 11 represent an additional 3-way ANOVA performed on the same data, but including the year by site interaction. Analogous information for the hardwood stands is presented in Tables 12 - 15.

Individual pine fascicles placed in the ground or control plantation decomposed faster than those placed in the antenna plantation. The individual pine fascicles placed in the control and antenna hardwood stands decomposed at the same rate. Comparing years in the plantations, 1987 and 1988 samples decomposed fastest (n.s.d., $\alpha = 0.05$) and 1985 samples slowest. In the hardwood stands, 1985 samples decomposed fastest and 1989 samples slowest; 1986 and 1988 samples decomposed similarly. Significant monthly progress occurred in the plantations, while progress in the hardwood stands occurred from June through October. Detectable differences were extremely low, well below 1 percent of the yearly, monthly and subunit mean values. This accounts for the significance of some of the differences between very close mean values. The year by site interactions were highly significant for both the plantation and hardwood stand analyses, but neither the results of multiple comparisons nor the magnitude of detectable differences was much affected by adding

Table 8. ANOVA table for detection of differences in dry matter mass loss (arcsin square root of the proportion of initial mass remaining) from **individual pine** needles in the three **plantation** subunits, by year, sampling date, and subunit, and without the use of covariates.

Source of Variation	df	SS	Type III SS	F	Signif. of F	r^2
Model	12	23.60		806.61	0.0000	0.81
Year	4		0.30	31.01	0.0001	
Month	6		23.11	1580.32	0.0000	
Plantation	2		0.07	13.60	0.0001	
Error	2340	5.70				
Corrected Total	2352	29.30				

Table 9. Adjusted means, standard errors, detectable differences, and significantly different pairs of means, based on the model analyzed in Table 8.

Source of Variation	Adjusted Mean[a]	Standard Error	Detectable Difference[b]	Significant Differences[c]						
Year					5	6	7	8		
1985	1.168	0.002	0.34	1985						
1986	1.155	0.002	0.34	1986	*					
1987	1.141	0.002	0.34	1987	*	*				
1988	1.139	0.002	0.34	1988	*	*				
1989	1.161	0.002	0.34	1989	*	*	*	*		
Month					1	2	3	4	5	6
May	1.293	0.004	0.61	May						
June	1.261	0.004	0.62	June	*					
July	1.205	0.004	0.65	July	*	*				
August	1.160	0.004	0.68	Aug	*	*	*			
September	1.090	0.003	0.54	Sept	*	*	*	*		
October	1.044	0.003	0.56	Oct	*	*	*	*	*	
November	1.016	0.003	0.58	Nov	*	*	*	*	*	*
Plantation						G		A		C
Ground	1.149	0.002	0.34	Ground						
Antenna	1.159	0.002	0.34	Antenna		*				
Control	1.150	0.002	0.34	Control				*		

a/ mean of transformed data
b/ estimated shift in the sample mean which would be detected 95 percent of the time (α = .05), calculated as $t_{.05,n}$*S.E./Mean, and expressed as a percentage of the sample mean
c/ α = .05, Tukey's H.S.D.

Table 10. ANOVA table (including year * plantation interaction) for detection of differences in dry matter mass loss (arcsin square root of the proportion of initial mass remaining) from **individual pine** needles in the three **plantation** subunits, by year, sampling date, and subunit, and without the use of covariates.

Source of Variation	df	SS	Type III SS	F	Signif. of F	r^2
Model	20	23.70		493.29	0.0000	0.81
Year	4		0.30	30.82	0.0001	
Month	6		23.08	1601.39	0.0000	
Plantation	2		0.05	11.17	0.0001	
Year*Plantation	8		0.10	5.35	0.0001	
Error	2332	5.60				
Corrected Total	2352	29.30				

Table 11. Adjusted means, standard errors, detectable differences, and significantly different pairs of means, based on the model analyzed in Table 10.

Source of Variation	Adjusted Mean[a]	Standard Error	Detectable Difference[b]	Significant Differences[c]						
Year					5	6	7	8		
1985	1.168	0.002	0.34	1985						
1986	1.155	0.002	0.34	1986	*					
1987	1.141	0.002	0.34	1987	*	*				
1988	1.139	0.002	0.34	1988	*	*				
1989	1.161	0.002	0.34	1989	*	*	*	*		
Month					1	2	3	4	5	6
May	1.293	0.003	0.45	May						
June	1.261	0.003	0.47	June	*					
July	1.205	0.003	0.49	July	*	*				
August	1.160	0.003	0.51	Aug	*	*	*			
September	1.090	0.003	0.54	Sept	*	*	*	*		
October	1.044	0.003	0.56	Oct	*	*	*	*	*	
November	1.016	0.003	0.58	Nov	*	*	*	*	*	*
Plantation					G	A	C			
Ground	1.149	0.002	0.34	Ground						
Antenna	1.159	0.002	0.34	Antenna	*					
Control	1.150	0.002	0.34	Control		*				

a/ mean of transformed data
b/ estimated shift in the sample mean which would be detected 95 percent of the time (α = .05), calculated as $t_{.05,n}$*S.E./Mean, and expressed as a percentage of the sample mean
c/ α = .05, Tukey's H.S.D.

Table 12. ANOVA table for detection of differences in dry matter mass loss (arcsin square root of the proportion of initial mass remaining) from **individual pine** needles in the two **hardwood stand** subunits, by year, sampling date, and subunit, and without the use of covariates.

Source of Variation	df	SS	Type III SS	F	Signif. of F	r^2
Model	12	20.02		701.21	0.0000	0.82
Year	4		1.00	105.28	0.0000	
Month	7		18.81	1129.53	0.0000	
Hardwood Stand	1		0.00	0.15	0.6975	
Error	1909	4.54				
Corrected Total	1921	24.57				

Table 13. Adjusted means, standard errors, detectable differences, and significantly different pairs of means, based on the model analyzed in Table 12.

Source of Variation	Adjusted Mean[a]	Standard Error	Detectable Difference[b]	Significant Differences[c]							
Year					5	6	7	8			
1985	1.118	0.002	0.35	1985							
1986	1.168	0.002	0.34	1986	*						
1987	1.147	0.003	0.51	1987	*	*					
1988	1.166	0.003	0.50	1988	*		*				
1989	1.182	0.003	0.50	1989	*	*	*	*			
Month					1	2	3	4	5	6	7
May	1.295	0.003	0.45	May							
June	1.273	0.003	0.46	June							
July	1.236	0.003	0.48	July	*	*					
August	1.195	0.003	0.49	Aug	*	*	*				
September	1.110	0.003	0.53	Sept	*	*	*	*			
October	1.064	0.003	0.55	Oct	*	*	*	*	*		
November	1.037	0.003	0.57	Nov	*	*	*	*	*	*	
December	1.037	0.004	0.76	Dec	*	*	*	*	*	*	
Hardwood Stand					A	C					
Antenna	1.156	0.002	0.34	Antenna							
Control	1.156	0.002	0.34	Control							

a/ mean of transformed data
b/ estimated shift in the sample mean which would be detected 95 percent of the time ($\alpha = .05$), calculated as $t_{.05,n}$*S.E./Mean, and expressed as a percentage of the sample mean
c/ $\alpha = .05$, Tukey's H.S.D.

Table 14. ANOVA table (including year * stand interaction) for detection of differences in dry matter mass loss (arcsin square root of the proportion of initial mass remaining) from **individual pine** needles in the two **hardwood stand** subunits, by year, sampling date, and subunit, and without the use of covariates.

Source of Variation	df	SS	Type III SS	F	Signif. of F	r^2
Model	16	20.46		593.77	0.0000	0.83
Year	4		1.01	116.68	0.0000	
Month	7		18.81	1247.34	0.0000	
Hardwood Stand	1		0.00	1.36	0.2430	
Year * Stand	4		0.44	51.01	0.0001	
Error	1905	4.10				
Corrected Total	1921	24.57				

Table 15. Adjusted means, standard errors, detectable differences, and significantly different pairs of means, based on the model analyzed in Table 14.

Source of Variation	Adjusted Mean[a]	Standard Error	Detectable Difference[b]	Significant Differences[c]							
Year					5	6	7	8			
1985	1.118	0.002	0.35	1985							
1986	1.168	0.002	0.34	1986	*						
1987	1.147	0.003	0.51	1987	*	*					
1988	1.166	0.002	0.34	1988	*		*				
1989	1.182	0.002	0.33	1989	*	*	*	*			
Month					1	2	3	4	5	6	7
May	1.295	0.003	0.45	May							
June	1.273	0.003	0.46	June	*						
July	1.236	0.003	0.48	July	*	*					
August	1.196	0.003	0.49	Aug	*	*	*				
September	1.110	0.003	0.53	Sept	*	*	*	*			
October	1.065	0.003	0.55	Oct	*	*	*	*	*		
November	1.037	0.003	0.57	Nov	*	*	*	*	*	*	
December	1.037	0.003	0.57	Dec	*	*	*	*	*	*	*
Hardwood Stand							A		C		
Antenna	1.155	0.002	0.34	Antenna							
Control	1.157	0.002	0.34	Control							

a/ mean of transformed data

b/ estimated shift in the sample mean which would be detected 95 percent of the time ($\alpha = .05$), calculated as $t_{.05,n}$*S.E./Mean, and expressed as a percentage of the sample mean

c/ $\alpha = .05$, Tukey's H.S.D.

the interaction to the analyses.

Figures 1 and 2 present comparisons of monthly dry matter mass loss progress during the 1988-89 study on the plantation and hardwood stand subunits, respectively. Means representing the raw (untransformed) data are plotted between bars depicting their associated 95 percent confidence intervals. The similarity among plantation and hardwood stand subunits is encouraging, and suggests that ANACOV may explain the differences detected by ANOVA. As mentioned in previous reports, some of the differences detected between subunits by ANOVA would be difficult to anticipate from these figures. Again, we note that the single sample error limits depicted in the figures are much more conservative than is ANOVA.

Figure 3 presents comparisons of monthly dry matter mass loss progress during the 1984-85 through 1988-89 studies on the ground unit plantation. Again, means are plotted between bars depicting their associated 95 percent confidence intervals. Figures 4 through 7 present corresponding comparisons for the antenna and control unit plantations and for the antenna and control unit hardwood stands, respectively. While the significant differences detected by ANOVA are apparent, the differences between annual studies are not particularly striking, and suggest that ANACOV may explain them.

Individual Oak Leaves

Tables 16 - 19 and 20 - 23 present the results of ANOVA for the plantation and hardwood stand subunits, respectively. No differences were detected in decomposition rate among the three study plantations. However, decomposition has proceeded faster in the antenna hardwood stand than in the control hardwood stand. Comparing years in the plantations, 1987 samples decomposed fastest and 1986 samples slowest; decomposition rates in 1988 and 1989 were similar. In the hardwood stands, 1989 samples decomposed fastest and 1986 samples decomposed slowest; decomposition proceeded similarly in 1985 and 1987, and also in 1987 and 1988. Significant monthly progress occurred in the plantations; except in November, significant monthly progress was also made in the hardwood stands. Detectable differences were very low, below 1.2 percent for yearly, monthly, and subunit mean values. The year by site interactions were highly significant in both the plantations and hardwood stands. While these interactions had no apparent effect on treatment means or detectable differences, the difference between 1988 and 1989 became significant in the plantations with inclusion of the interaction (all yearly comparisons are now significant). In the hardwood stands, the interaction resulted in an indication of significant decomposition progress during November.

Figures 8 and 9 present comparisons of monthly progress in dry matter mass loss during the 1988-89 study on the plantation and hardwood stand subunits, respectively. Means representing the raw (untransformed) data are plotted between bars depicting their associated 95 percent confidence intervals. As with the

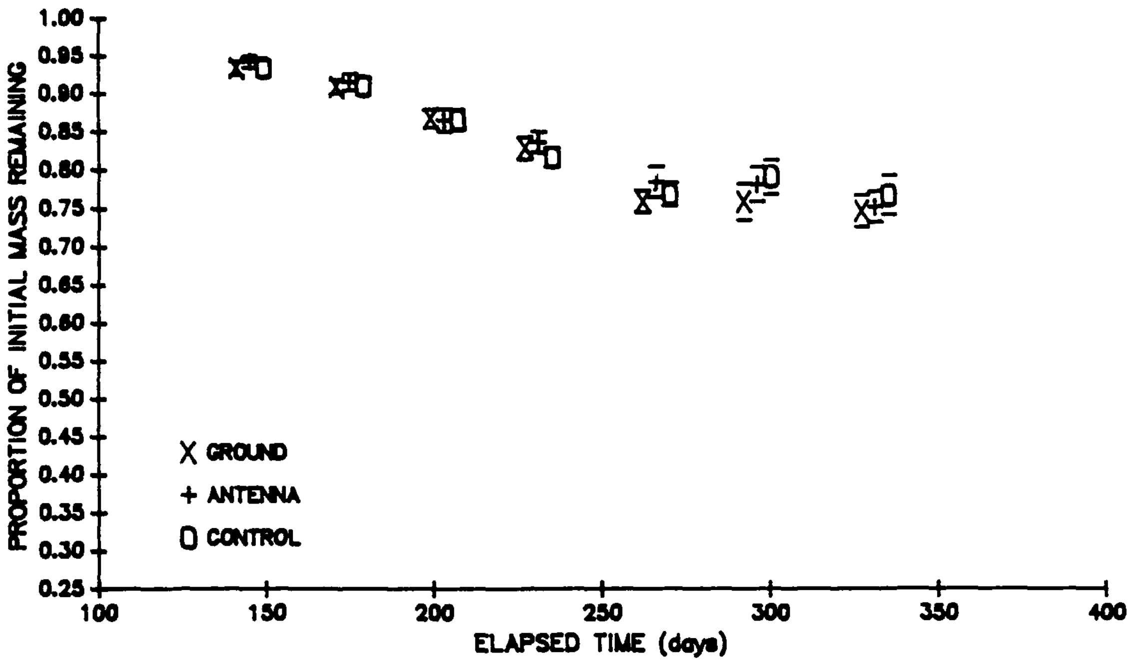


FIGURE 1. Proportion (X) of initial dry matter mass remaining for individual pine fascicle samples retrieved from the three plantation subunits during the 1988–1989 experiment.

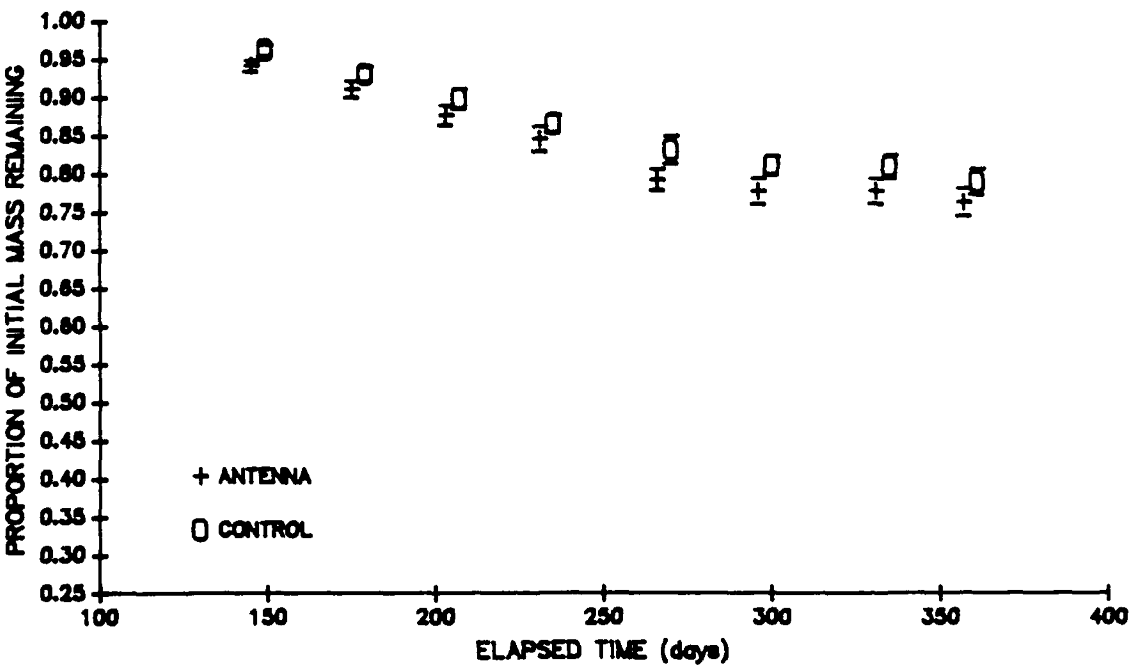


FIGURE 2. Proportion (X) of initial dry matter mass remaining for individual pine fascicle samples retrieved from the two hardwood stand subunits during the 1988–1989 experiment.

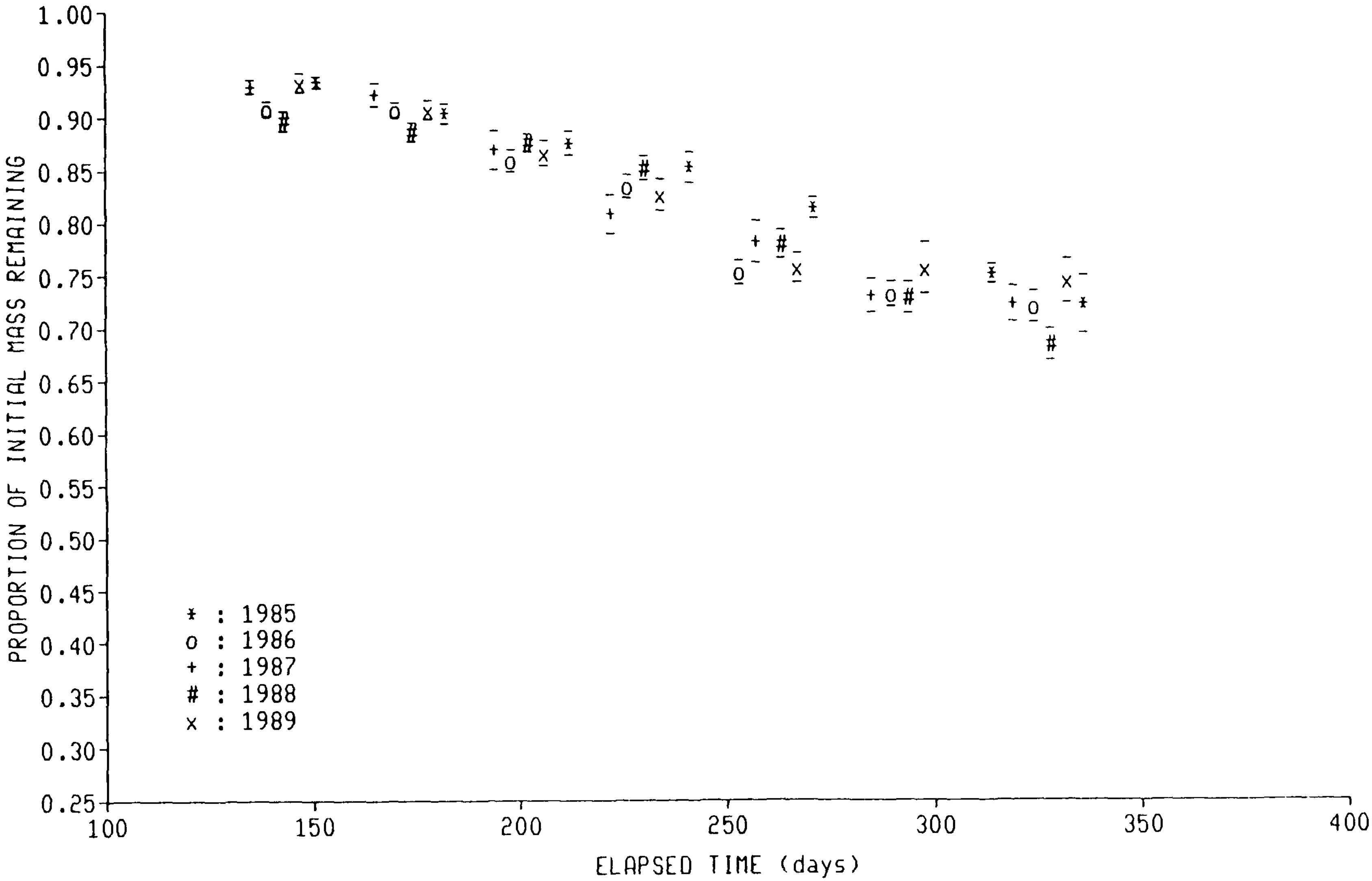


Figure 3. Proportion (X) of initial dry matter mass remaining for individual pine fascicle samples retrieved from the ground unit plantation during the five consecutive annual experiments completed to date.

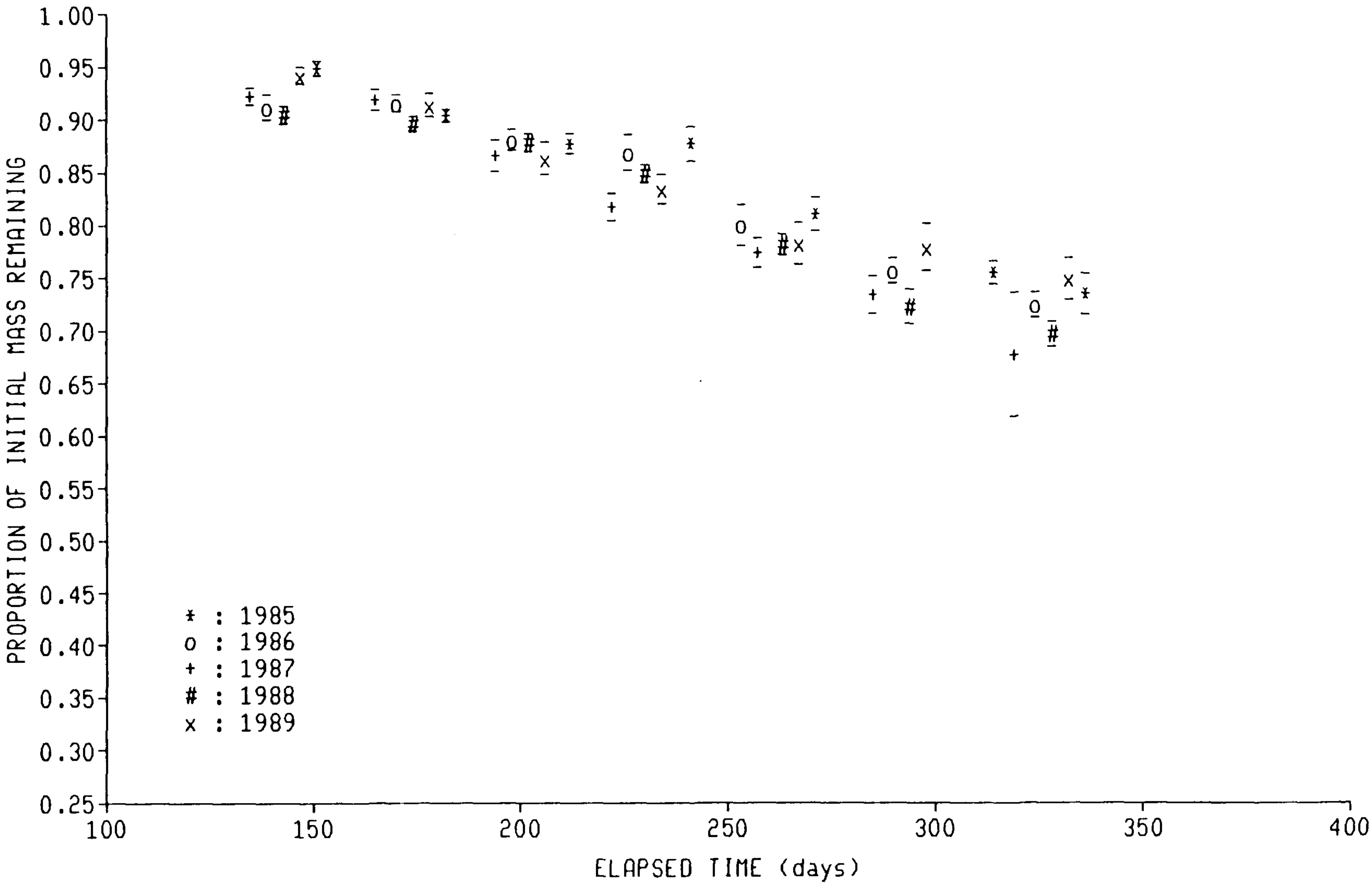


Figure 4. Proportion (X) of initial dry matter mass remaining for individual pine fascicle samples retrieved from the antenna unit plantation during the five consecutive annual experiments completed to date.

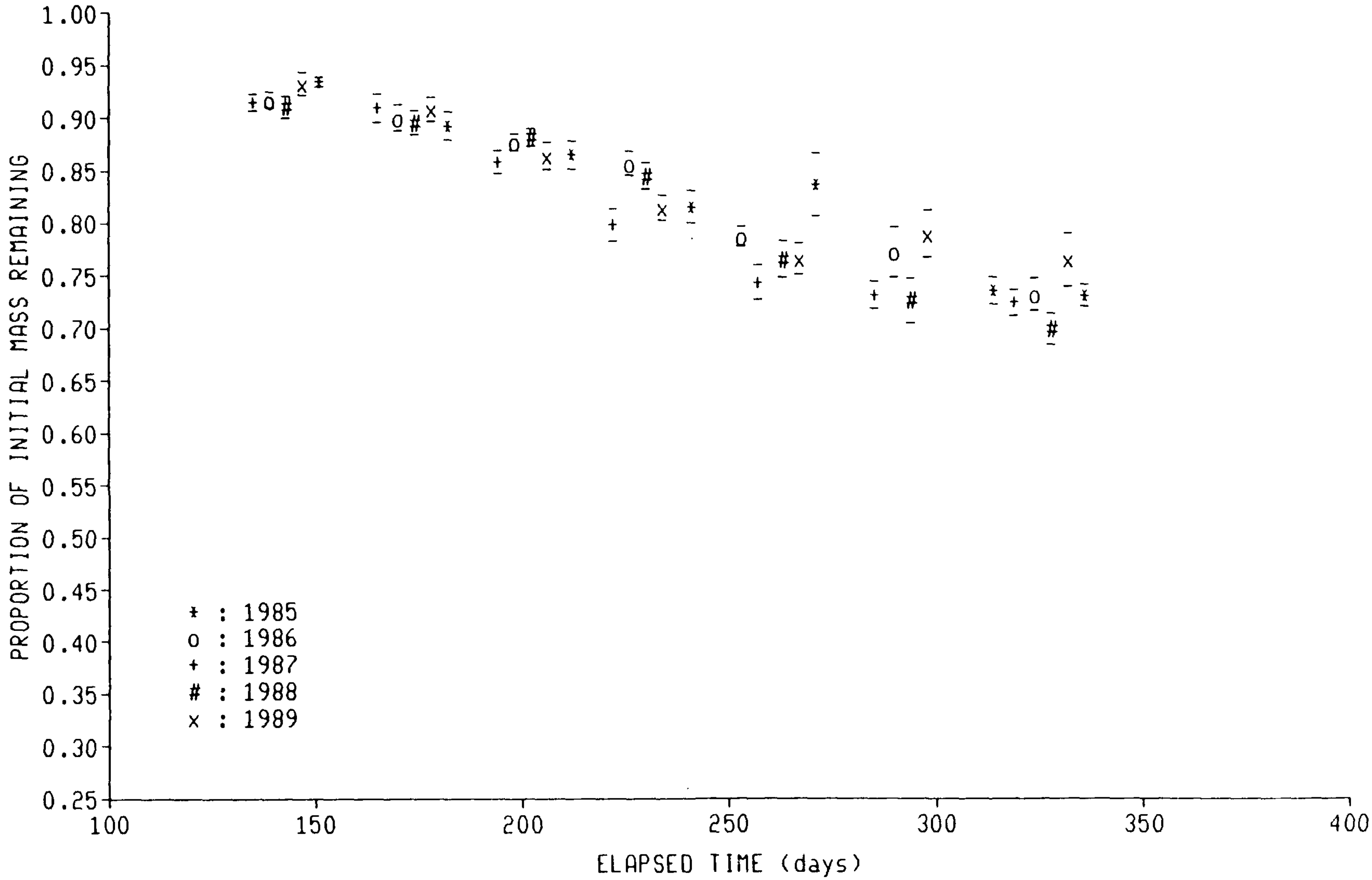


Figure 5. Proportion (X) of initial dry matter mass remaining for individual pine fascicle samples retrieved from the control unit plantation during the five consecutive annual experiments completed to date.

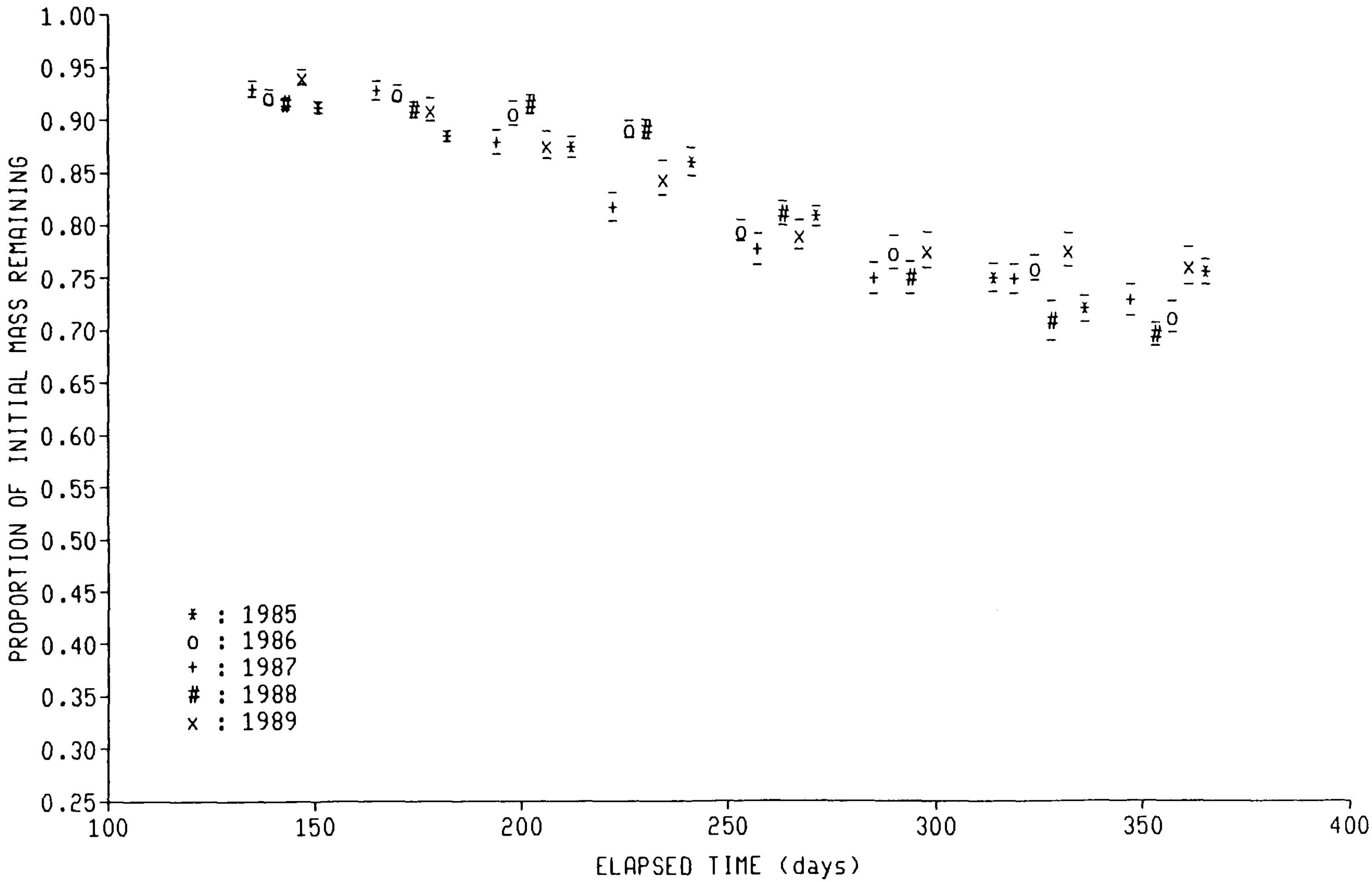


Figure 6. Proportion (X) of initial dry matter mass remaining for individual pine fascicle samples retrieved from the antenna unit hardwood stand during the five consecutive annual experiments completed to date.

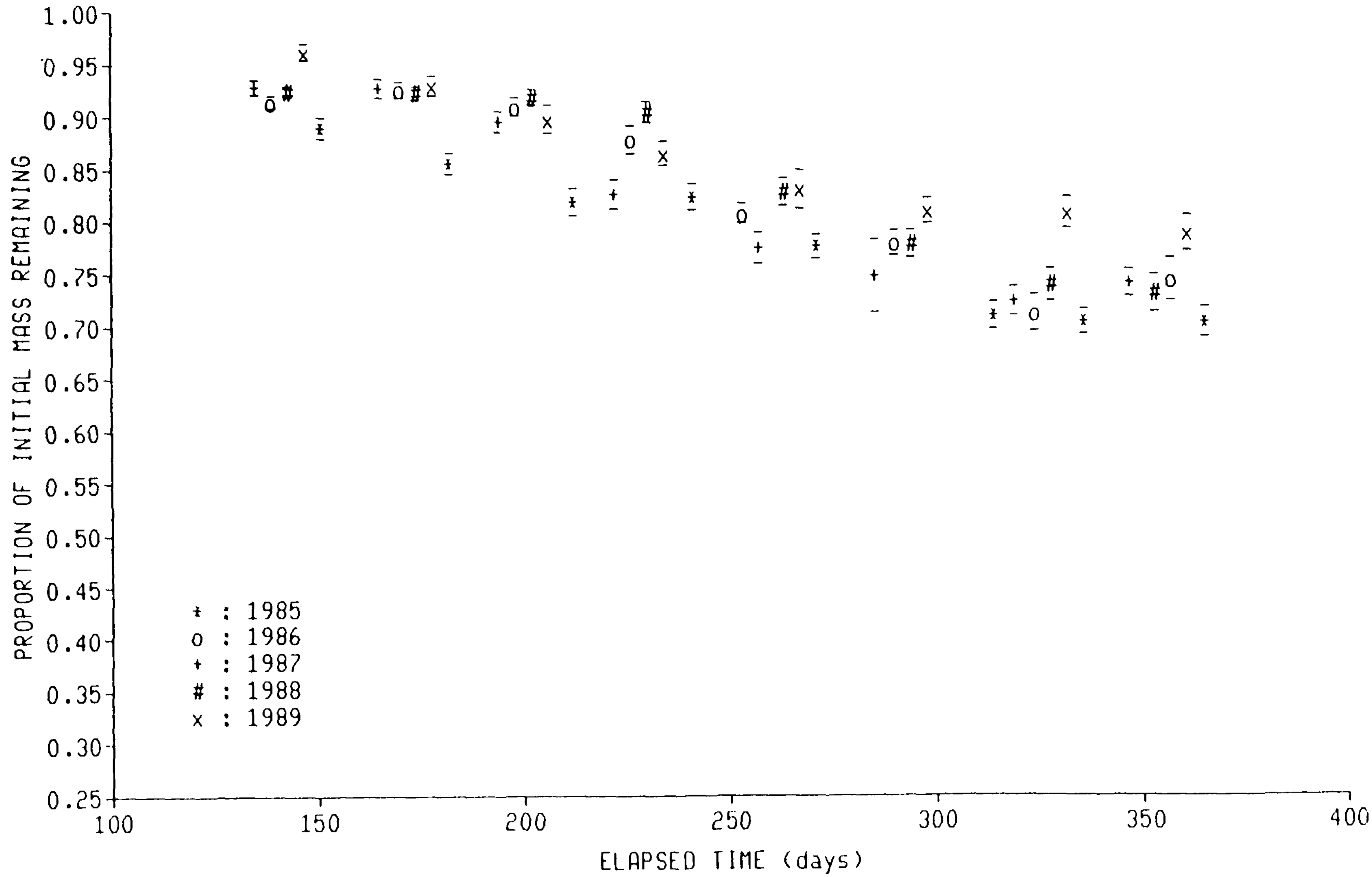


Figure 7. Proportion (X) of initial dry matter mass remaining for individual pine fascicle samples retrieved from the control unit hardwood stand during the five consecutive annual experiments completed to date.

Table 16. ANOVA table for detection of differences in dry matter mass loss (arcsin square root of the proportion of initial mass remaining) from **individual oak** leaves in the three **plantation** subunits, by year, sampling date, and subunit, and without the use of covariates.

Source of Variation	df	SS	Type III SS	F	Signif. of F	r^2
Model	12	64.40		512.04	0.0000	0.69
Year	4		11.71	279.31	0.0000	
Month	6		53.07	844.00	0.0000	
Plantation	2		0.06	2.69	0.0681	
Error	2714	28.44				
Corrected Total	2726	92.84				

Table 17. Adjusted means, standard errors, detectable differences, and significantly different pairs of means, based on the model analyzed in Table 16.

Source of Variation	Adjusted Mean[a]	Standard Error	Detectable Difference[b]	Significant Differences[c]						
Year					5	6	7	8		
1985	1.101	0.004	0.71	1985						
1986	1.157	0.004	0.68	1986	*					
1987	0.995	0.005	0.98	1987	*	*				
1988	1.008	0.005	0.97	1988	*	*	*			
1989	1.010	0.005	0.97	1989	*	*	*			
Month					1	2	3	4	5	6
May	1.283	0.005	0.76	May						
June	1.186	0.005	0.83	June	*					
July	1.119	0.005	0.88	July	*	*				
August	1.046	0.005	0.94	Aug	*	*	*			
September	0.966	0.005	1.01	Sept	*	*	*	*		
October	0.913	0.005	1.07	Oct	*	*	*	*	*	
November	0.868	0.005	1.13	Nov	*	*	*	*	*	*
Plantation						G	A	C		
Ground	1.050	0.003	0.56	Ground						
Antenna	1.053	0.003	0.56	Antenna						
Control	1.060	0.003	0.55	Control						

a/ mean of transformed data
b/ estimated shift in the sample mean which would be detected 95 percent of the time (α = .05), calculated as $t_{.05,n}$*S.E./Mean, and expressed as a percentage of the sample mean
c/ α = .05, Tukey's H.S.D.

Table 18. ANOVA table (including year * plantation interaction) for detection of differences in dry matter mass loss (arcsin square root of the proportion of initial mass remaining) from **individual oak** leaves in the three **plantation** subunits, by year, sampling date, and subunit, and without the use of covariates.

Source of Variation	df	SS	Type III SS	F	Signif. of F	r^2
Model	20	64.65		310.23	0.0000	0.70
Year	4		11.69	280.42	0.0000	
Month	6		53.06	848.76	0.0000	
Plantation	2		0.05	2.27	0.1040	
Year*Plantation	8		0.25	3.00	0.0024	
Error	2706	28.19				
Corrected Total	2726	92.84				

Table 19. Adjusted means, standard errors, detectable differences, and significantly different pairs of means, based on the model analyzed in Table 18.

Source of Variation	Adjusted Mean[a]	Standard Error	Detectable Difference[b]	Significant Differences[c]						
Year					5	6	7	8		
1985	1.101	0.004	0.71	1985						
1986	1.157	0.004	0.68	1986	*					
1987	0.995	0.005	0.98	1987	*	*				
1988	1.008	0.005	0.97	1988	*	*	*			
1989	1.010	0.005	0.97	1989	*	*	*	*		
Month					1	2	3	4	5	6
May	1.283	0.005	0.76	May						
June	1.186	0.005	0.83	June	*					
July	1.119	0.005	0.88	July	*	*				
August	1.046	0.005	0.94	Aug	*	*	*			
September	0.966	0.005	1.01	Sept	*	*	*	*		
October	0.913	0.005	1.07	Oct	*	*	*	*	*	
November	0.868	0.005	1.13	Nov	*	*	*	*	*	*
Plantation						G	A	C		
Ground	1.050	0.003	0.56	Ground						
Antenna	1.053	0.003	0.56	Antenna						
Control	1.060	0.003	0.55	Control						

a/ mean of transformed data
b/ estimated shift in the sample mean which would be detected 95 percent of the time (α = .05), calculated as $t_{.05,n}$*S.E./Mean, and expressed as a percentage of the sample mean
c/ α = .05, Tukey's H.S.D.

Table 20. ANOVA table for detection of differences in dry matter mass loss (arcsin square root of the proportion of initial mass remaining) from **individual oak** leaves in the two **hardwood stand** subunits, by year, sampling date, and location within the subunits, and without the use of covariates.

Source of Variation	df	SS	Type III SS	F	Signif. of F	r^2
Model	12	34.83		457.06	0.0000	0.73
Year	4		1.45	56.94	0.0001	
Month	7		33.10	744.60	0.0000	
Hardwood Stand	1		0.12	19.45	0.0001	
Error	2066	13.12				
Corrected Total	2078	47.95				

Table 21. Adjusted means, standard errors, detectable differences, and significantly different pairs of means, based on the model analyzed in Table 20.

Source of Variation	Adjusted Mean[a]	Standard Error	Detectable Difference[b]	Significant Differences[c]							
Year					5	6	7	8			
1985	1.121	0.004	0.70	1985							
1986	1.175	0.004	0.67	1986	*						
1987	1.127	0.004	0.70	1987		*					
1988	1.135	0.004	0.69	1988	*	*					
1989	1.095	0.004	0.72	1989	*	*	*	*			
Month					1	2	3	4	5	6	7
May	1.312	0.005	0.75	May							
June	1.264	0.005	0.78	June	*						
July	1.235	0.005	0.79	July	*	*					
August	1.175	0.005	0.33	Aug	*	*	*				
September	1.093	0.005	0.90	Sept	*	*	*	*			
October	1.025	0.005	0.96	Oct	*	*	*	*	*		
November	0.969	0.005	1.01	Nov	*	*	*	*	*	*	
December	0.969	0.005	1.01	Dec	*	*	*	*	*	*	
Hardwood Stand					A	C					
Antenna	1.123	0.002	0.35	Antenna							
Control	1.138	0.002	0.34	Control	*						

a/ mean of transformed data
b/ estimated shift in the sample mean which would be detected 95 percent of the time (α = .05), calculated as $t_{.05,n}$*S.E./Mean, and expressed as a percentage of the sample mean
c/ α = .05, Tukey's H.S.D.

Table 22. ANOVA table (including year * stand interaction) for detection of differences in dry matter mass loss (arcsin square root of the proportion of initial mass remaining) from **individual oak** leaves in the two **hardwood stand** subunits, by year, sampling date, and subunit, and without the use of covariates.

Source of Variation	df	SS	Type III SS	F	Signif. of F	r^2
Model	16	35.41		364.15	0.0000	0.74
Year	4		1.46	60.14	0.0001	
Month	7		33.04	776.67	0.0000	
Hardwood Stand	1		0.16	26.50	0.0001	
Year * Stand	4		0.59	24.10	0.0001	
Error	2062	12.53				
Corrected Total	2078	47.95				

Table 23. Adjusted means, standard errors, detectable differences, and significantly different pairs of means, based on the model analyzed in Table 22.

Source of Variation	Adjusted Mean[a]	Standard Error	Detectable Difference[b]	Significant Differences[c]							
Year					5	6	7	8			
1985	1.121	0.004	0.70	1985							
1986	1.175	0.004	0.67	1986	*						
1987	1.127	0.004	0.70	1987		*					
1988	1.135	0.004	0.69	1988	*	*					
1989	1.095	0.004	0.72	1989	*	*	*	*			
Month					1	2	3	4	5	6	7
May	1.312	0.005	0.75	May							
June	1.264	0.005	0.78	June	*						
July	1.235	0.005	0.79	July	*	*					
August	1.175	0.005	0.83	Aug	*	*	*				
September	1.092	0.005	0.90	Sept	*	*	*	*			
October	1.025	0.005	0.96	Oct	*	*	*	*	*		
November	0.969	0.005	1.01	Nov	*	*	*	*	*	*	
December	0 970	0.005	1.01	Dec	*	*	*	*	*	*	*
Hardwood Stand					A	C					
Antenna	1.122	0.002	0.35	Antenna							
Control	1.139	0.002	0.34	Control	*						

a/ mean of transformed data

b/ estimated shift in the sample mean which would be detected 95 percent of the time (α = .05), calculated as $t_{.05,n}$*S.E./Mean, and expressed as a percentage of the sample mean

c/ α = .05, Tukey's H.S.D.

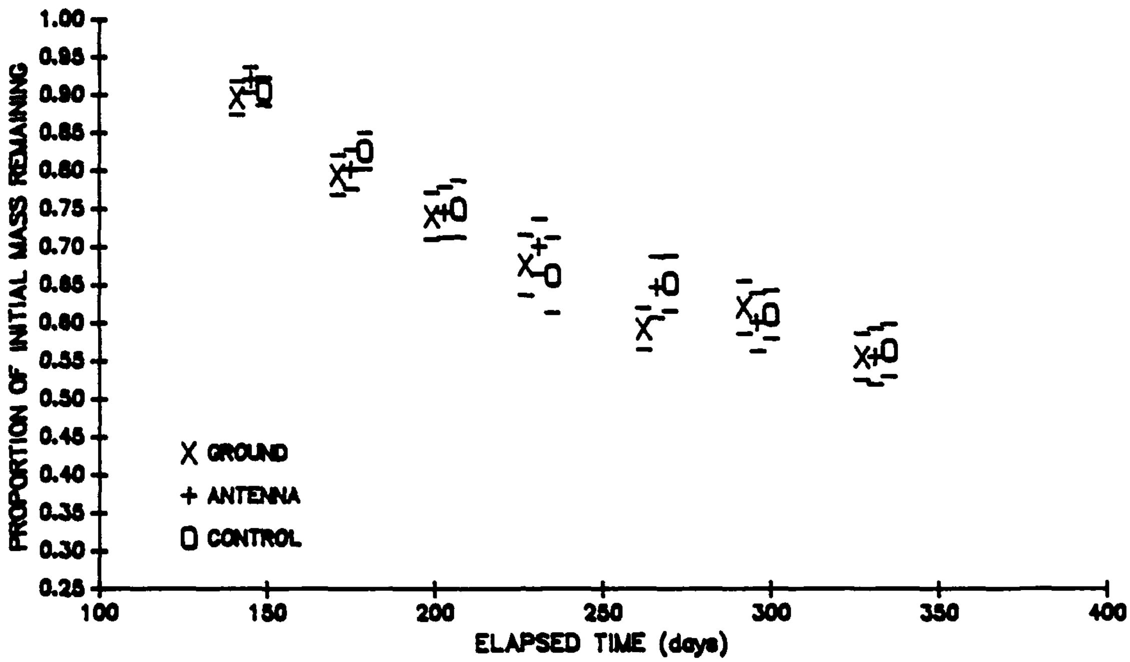


FIGURE 8. Proportion (X) of initial dry matter mass remaining for individual oak leaf samples retrieved from the three plantation subunits during the 1988–1989 experiment.

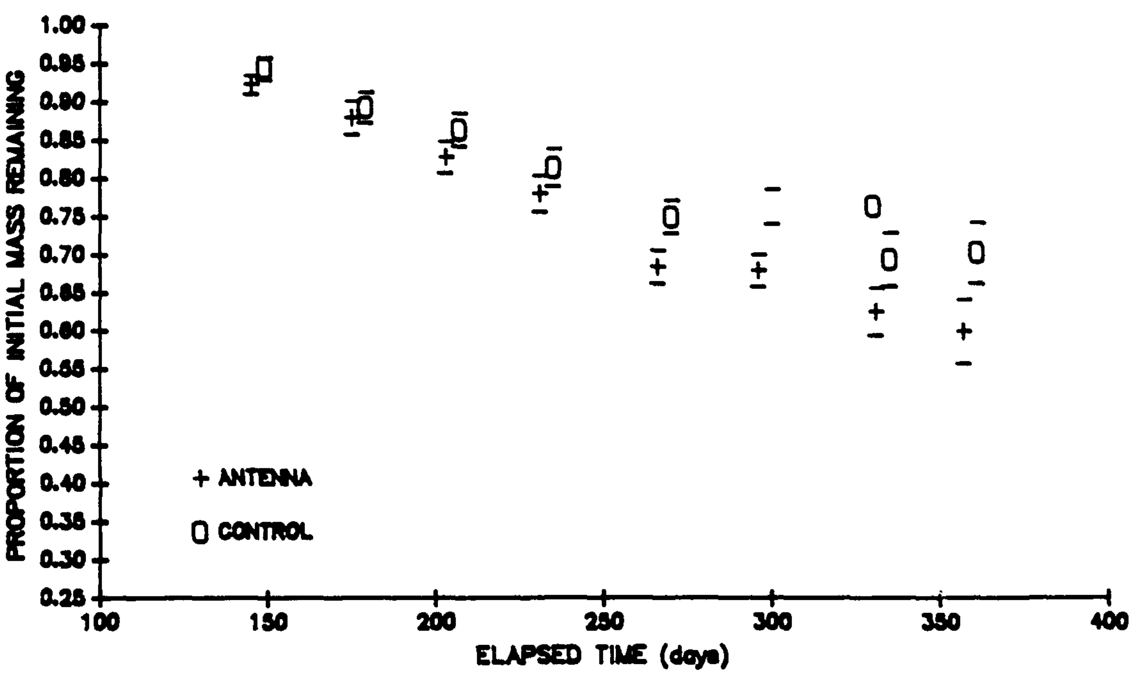


FIGURE 9. Proportion (X) of initial dry matter mass remaining for individual oak leaf samples retrieved from the two hardwood stand subunits during the 1988–1989 experiment.

individual pine fascicles, the similarity in oak leaf decomposition among plantation and hardwood stand subunits is encouraging. In 1989, decomposition appears to have proceeded slightly faster in the antenna site hardwood stand than in the control site hardwood stand, but the difference was not significant over all years, as seen by the ANOVA.

Figure 10 presents comparisons of monthly dry matter mass loss progress during the 1984-85 through 1988-89 studies on the ground unit plantation. Again, means are plotted between bars depicting their associated 95 percent confidence intervals. Figures 11 through 14 present corresponding comparisons for the antenna and control unit plantations and for the antenna and control unit hardwood stands. The significant differences detected by ANOVA are apparent, with the 1986-87 and 1987-88 studies in all three plantations standing out especially. The sampling method for individual oak (and pine) leaves was changed in time for the 1986-87 study, in order to permit truly independent sampling across the study subunits. Instead of collecting multiple tethered leaves in a single envelope from a few locations, larger numbers of envelopes are now collected on each sampling date, each containing only one oak leaf and one pine needle fascicle. One apparent effect of this change in method has been to expose individual leaves and fascicles more uniformly to weathering, because there is less opportunity now for individuals within an envelope to protect one another from the elements. It should be noted that individual pine fascicles placed in the three plantations also decomposed more rapidly during the 1986-87 and 1987-88 studies than in earlier years. The differences between years detected by ANOVA for mass loss from individual oak leaves and pine needles in the hardwood stands do not fit the same pattern. However, samples within the hardwood stands are not exposed to the same intensity of weathering as those in the plantation environment.

ANOVA Results - Bulk Leaf Litter Samples

Bulk Pine Needle Litter

Tables 24 - 27 and 28 - 31 present the results of ANOVA for the plantation and hardwood stand subunits, respectively. Bulk pine needles decomposed faster in the ground and control plantations than in the antenna plantation. However, similar samples have decomposed faster in the antenna hardwood stand than in the control stand. Comparing years in the plantations, 1985 samples decomposed fastest and 1987 samples slowest. In the hardwood stands, 1985 samples decomposed fastest and 1988 samples slowest; samples decomposed at similar rates in 1986 and 1987, and in 1987 and 1989. Significant monthly progress occurred in the plantations, while monthly progress in the hardwood stands occurred from May through October. Detectable differences were extremely low, below 1 percent of the yearly, monthly and subunit mean values. This accounts for some of the very small differences between mean values which are nevertheless

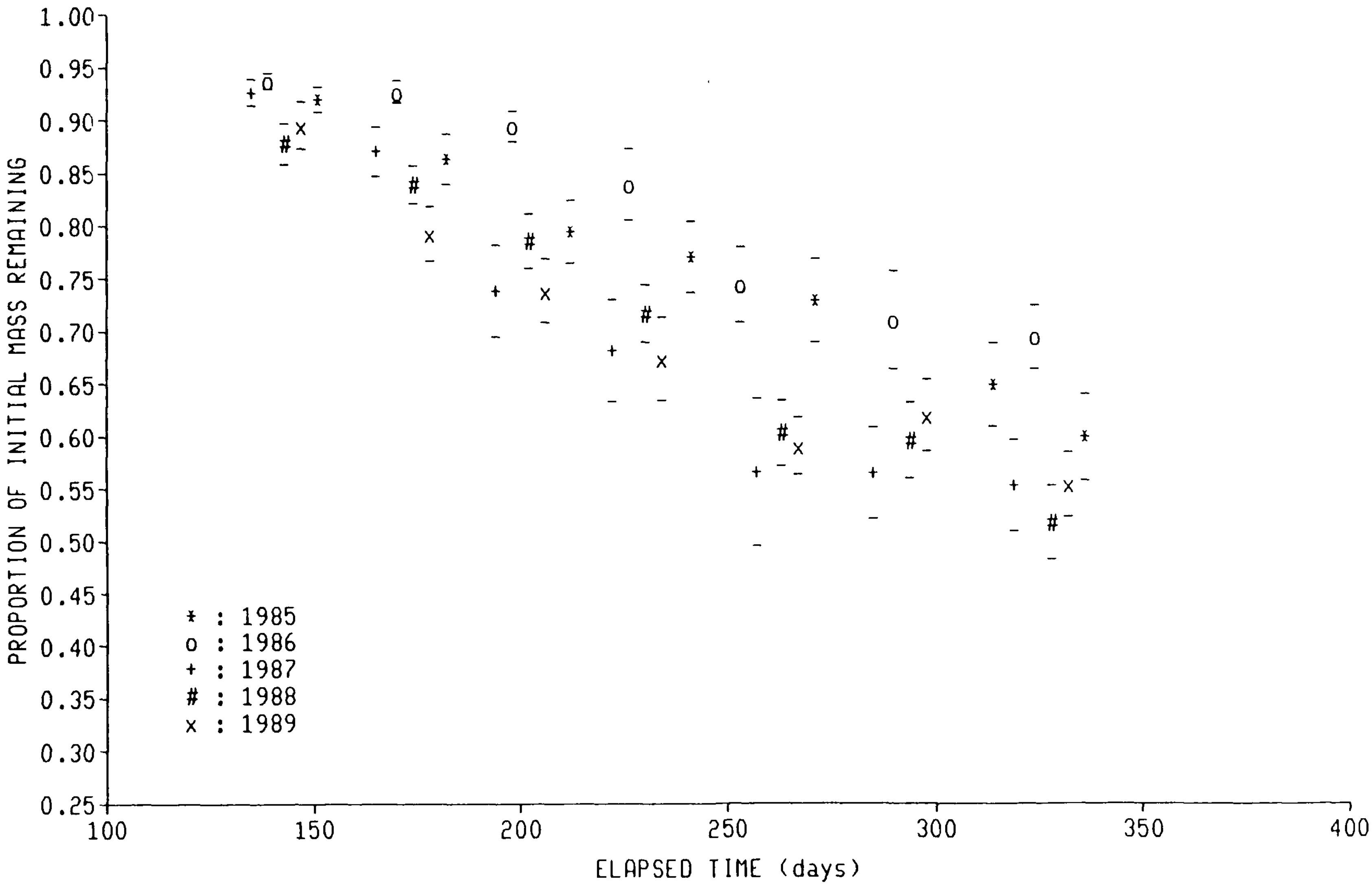


Figure 10. Proportion (X) of initial dry matter mass remaining for individual oak leaf samples retrieved from the ground unit plantation during the five consecutive annual experiments completed to date.

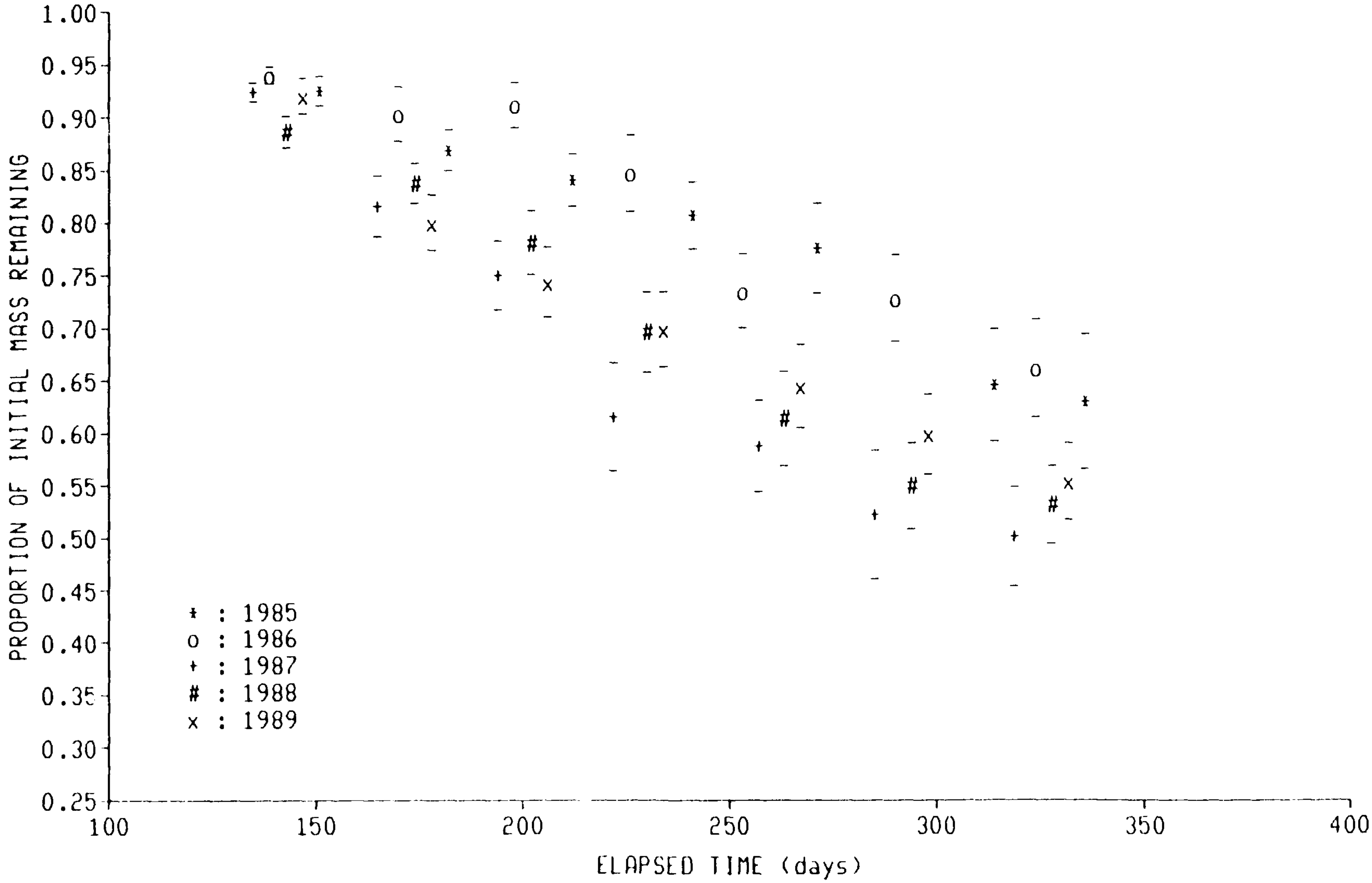


Figure 11. Proportion (X) of initial dry matter mass remaining for individual oak leaf samples retrieved from the antenna unit plantation during the five consecutive annual experiments completed to date.

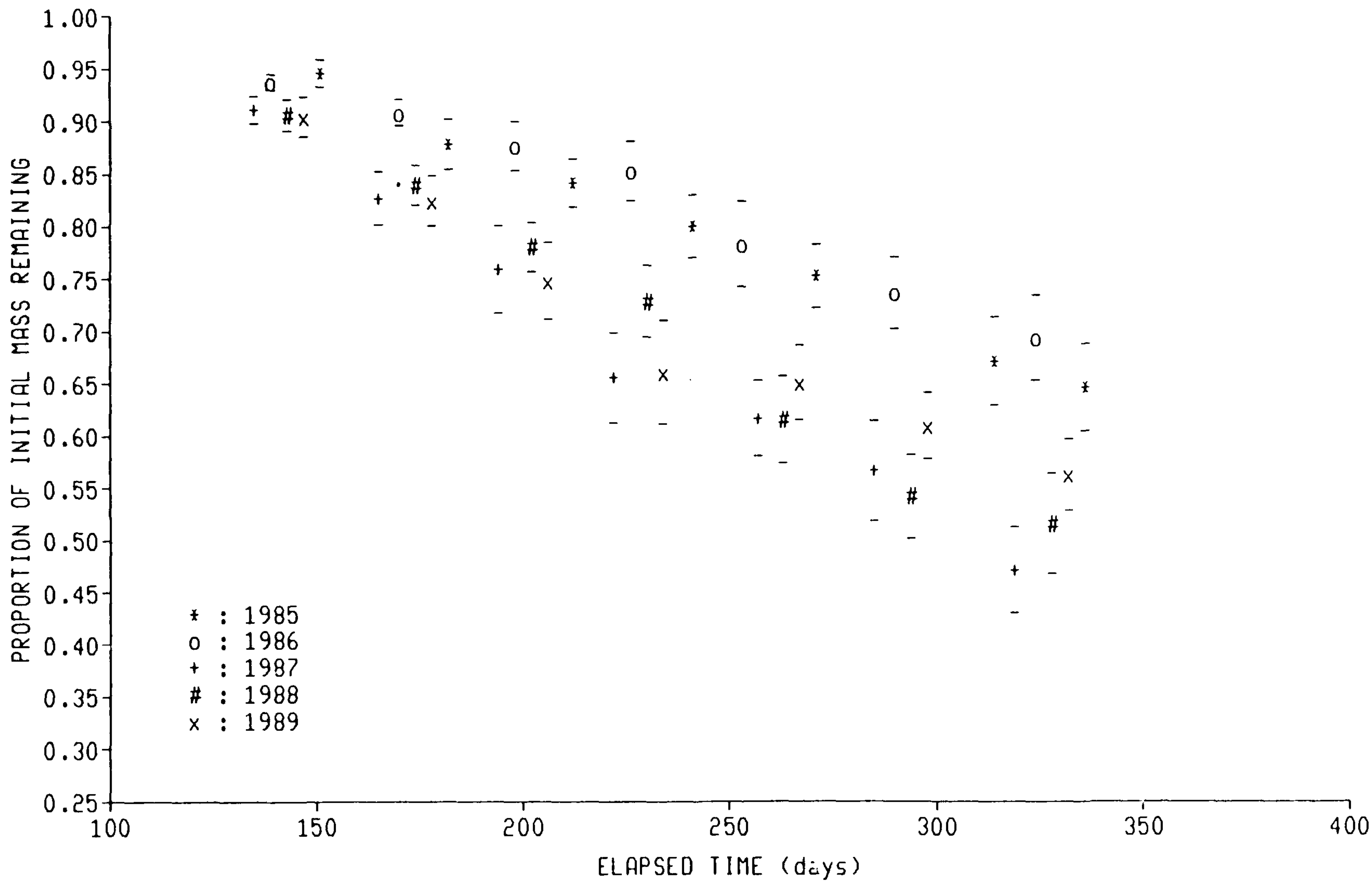


Figure 12. Proportion (X) of initial dry matter mass remaining for individual oak leaf samples retrieved from the control unit plantation during the five consecutive annual experiments completed to date.

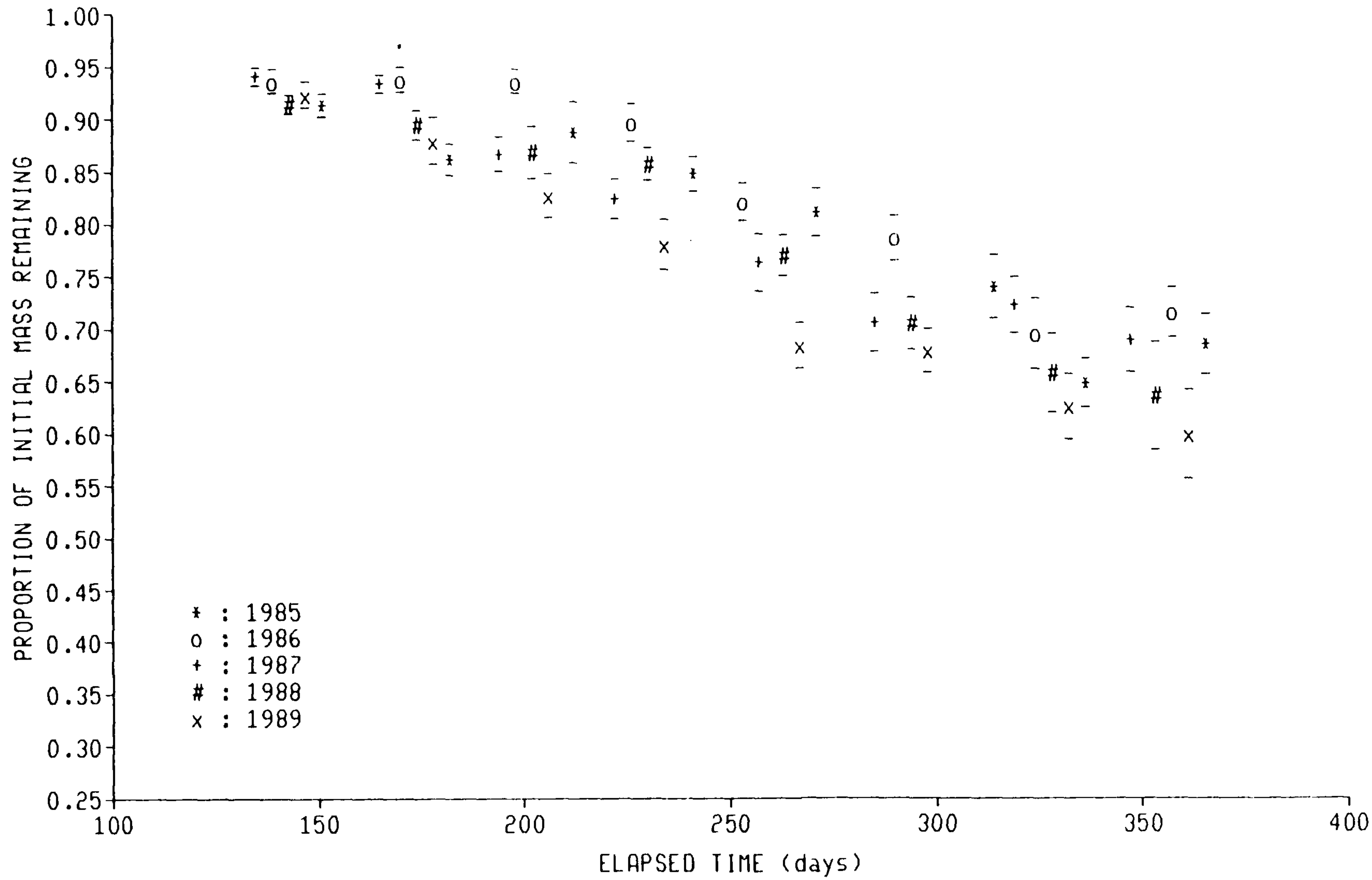


Figure 13. Proportion (X) of initial dry matter mass remaining for individual oak leaf samples retrieved from the antenna unit hardwood stand during the five consecutive annual experiments completed to date.

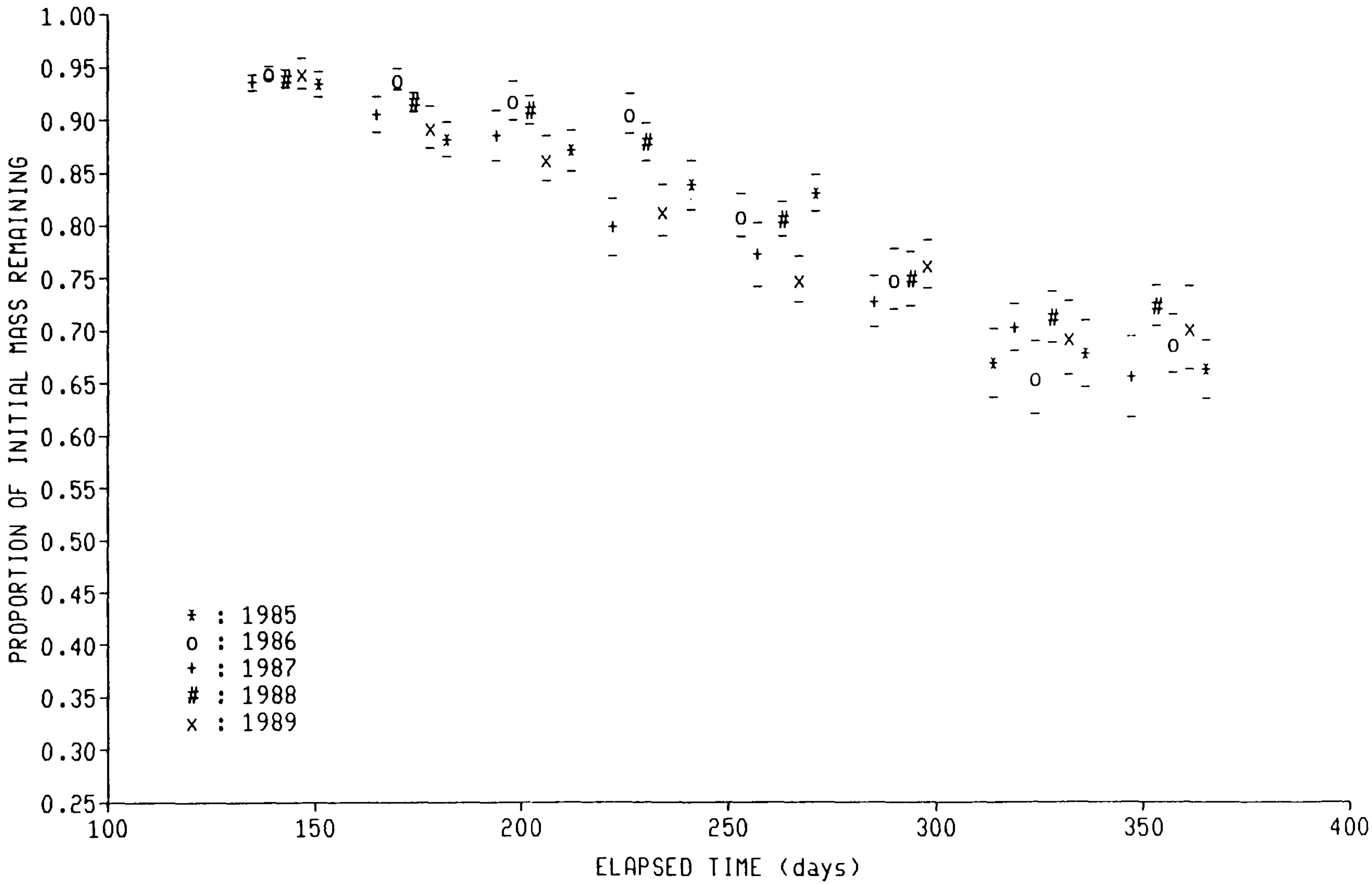


Figure 14. Proportion (X) of initial dry matter mass remaining for individual oak leaf samples retrieved from the control unit hardwood stand during the five consecutive annual experiments completed to date.

Table 24. ANOVA table for detection of differences in dry matter mass loss (arcsin square root of the proportion of initial mass remaining) from **bulk pine** needle samples in the three **plantation** subunits, by year, sampling date, and subunit, and without the use of covariates.

Source of Variation	df	SS	Type III SS	F	Signif. of F	r^2
Model	12	5.26		372.56	0.0000	0.88
Year	4		0.20	41.70	0.0001	
Month	6		5.01	709.55	0.0000	
Plantation	2		0.05	23.34	0.0001	
Error	617	0.73				
Corrected Total	629	5.98				

Table 25. Adjusted means, standard errors, detectable differences, and significantly different pairs of means, based on the model analyzed in Table 24.

Source of Variation	Adjusted Mean[a]	Standard Error	Detectable Difference[b]	Significant Differences[c]						
Year					5	6	7	8		
1985	1.120	0.003	0.53	1985						
1986	1.148	0.003	0.51	1986	*					
1987	1.171	0.003	0.50	1987	*	*				
1988	1.161	0.003	0.51	1988	*	*	*			
1989	1.138	0.003	0.52	1989	*	*	*	*		
Month					1	2	3	4	5	6
May	1.273	0.004	0.62	May						
June	1.233	0.004	0.64	June	*					
July	1.205	0.004	0.65	July	*	*				
August	1.162	0.004	0.67	Aug	*	*	*			
September	1.094	0.004	0.72	Sept	*	*	*	*		
October	1.041	0.004	0.75	Oct	*	*	*	*	*	
November	1.026	0.004	0.76	Nov	*	*	*	*	*	*
Plantation					G	A	C			
Ground	1.141	0.002	0.34	Ground						
Antenna	1.161	0.002	0.34	Antenna	*					
Control	1.141	0.002	0.34	Control		*				

a/ mean of transformed data

b/ estimated shift in the sample mean which would be detected 95 percent of the time (α = .05), calculated as $t_{.05,n}$*S.E./Mean, and expressed as a percentage of the sample mean

c/ α = .05, Tukey's H.S.D.

Table 26. ANOVA table (including year * plantation interaction) for detection of differences in dry matter mass loss (arcsin square root of the proportion of initial mass remaining) from **bulk pine** needle samples in the three **plantation** subunits, by year, sampling date, and subunit, and without the use of covariates.

Source of Variation	df	SS	Type III SS	F	Signif. of F	r^2
Model	20	5.29		230.54	0.0000	0.88
Year	4		0.20	42.79	0.0001	
Month	6		5.01	727.97	0.0000	
Plantation	2		0.05	23.95	0.0001	
Year*Plantation	8		0.03	3.00	0.0026	
Error	609	0.70				
Corrected Total	629	5.98				

Table 27. Adjusted means, standard errors, detectable differences, and significantly different pairs of means, based on the model analyzed in Table 26.

Source of Variation	Adjusted Mean[a]	Standard Error	Detectable Difference[b]	Significant Differences[c]						
Year					5	6	7	8		
1985	1.120	0.003	0.53	1985						
1986	1.148	0.003	0.51	1986	*					
1987	1.171	0.003	0.50	1987	*	*				
1988	1.161	0.003	0.51	1988	*	*	*			
1989	1.138	0.003	0.52	1989	*	*	*	*		
Month					1	2	3	4	5	6
May	1.273	0.004	0.62	May						
June	1.233	0.004	0.64	June	*					
July	1.205	0.004	0.65	July	*	*				
August	1.162	0.004	0.67	Aug	*	*	*			
September	1.094	0.004	0.72	Sept	*	*	*	*		
October	1.041	0.004	0.75	Oct	*	*	*	*	*	
November	1.026	0.004	0.76	Nov	*	*	*	*	*	*
Plantation					G	A	C			
Ground	1.141	0.002	0.34	Ground						
Antenna	1.161	0.002	0.34	Antenna	*					
Control	1.141	0.002	0.34	Control		*				

a/ mean of transformed data
b/ estimated shift in the sample mean which would be detected 95 percent of the time (α = .05), calculated as $t_{.05,n}$*S.E./Mean, and expressed as a percentage of the sample mean
c/ α = .05, Tukey's H.S.D.

Table 28. ANOVA table for detection of differences in dry matter mass loss (arcsin square root of the proportion of initial mass remaining) from **bulk pine** needle samples in the two **hardwood stand** subunits, by year, sampling date, and subunit, and without the use of covariates.

Source of Variation	df	SS	Type III SS	F	Signif. of F	r^2
Model	12	4.89		386.98	0.0000	0.91
Year	4		0.23	55.05	0.0001	
Month	7		4.63	627.27	0.0000	
Hardwood Stand	1		0.01	10.57	0.0014	
Error	453	0.48				
Corrected Total	465	5.37				

Table 29. Adjusted means, standard errors, detectable differences, and significantly different pairs of means, based on the model analyzed in Table 28.

Source of Variation	Adjusted Mean[a]	Standard Error	Detectable Difference[b]	Significant Differences[c]							
Year					5	6	7	8			
1985	1.094	0.003	0.54	1985							
1986	1.148	0.003	0.51	1986	*						
1987	1.140	0.003	0.52	1987	*						
1988	1.160	0.003	0.51	1988	*	*	*				
1989	1.133	0.004	0.69	1989	*	*		*			
Month					1	2	3	4	5	6	7
May	1.287	0.004	0.61	May							
June	1.244	0.004	0.63	June	*						
July	1.214	0.004	0.65	July	*	*					
August	1.170	0.004	0.67	Aug	*	*	*				
September	1.088	0.004	0.72	Sept	*	*	*	*			
October	1.043	0.004	0.75	Oct	*	*	*	*	*		
November	1.025	0.004	0.76	Nov	*	*	*	*	*		
December	1.009	0.005	0.97	Dec	*	*	*	*	*	*	
Hardwood Stand					A	C					
Antenna	1.130	0.002	0.35	Antenna		*					
Control	1.140	0.002	0.34	Control							

a/ mean of transformed data
b/ estimated shift in the sample mean which would be detected 95 percent of the time (α = .05), calculated as $t_{.05,n}$*S.E./Mean, and expressed as a percentage of the sample mean
c/ α = .05, Tukey's H.S.D.

Table 30. ANOVA table (including year * stand interaction) for detection of differences in dry matter mass loss (arcsin square root of the proportion of initial mass remaining) from **bulk pine** needle samples in the two **hardwood stand** subunits, by year, sampling date, and subunit, and without the use of covariates.

Source of Variation	df	SS	Type III SS	F	Signif. of F	r^2
Model	16	4.94		320.47	0.0000	0.92
Year	4		0.24	61.17	0.0001	
Month	7		4.63	686.87	0.0000	
Hardwood Stand	1		0.01	12.05	0.0006	
Year * Stand	4		0.05	11.72	0.0001	
Error	449	0.43				
Corrected Total	465	5.37				

Table 31. Adjusted means, standard errors, detectable differences, and significantly different pairs of means, based on the model analyzed in Table 30.

Source of Variation	Adjusted Mean[a]	Standard Error	Detectable Difference[b]	Significant Differences[c]							
Year					5	6	7	8			
1985	1.094	0.003	0.54	1985							
1986	1.148	0.003	0.51	1986	*						
1987	1.140	0.003	0.52	1987	*						
1988	1.160	0.003	0.51	1988	*	*	*				
1989	1.133	0.003	0.52	1989	*	*		*			
Month					1	2	3	4	5	6	7
May	1.287	0.004	0.61	May							
June	1.244	0.004	0.63	June	*						
July	1.214	0.004	0.65	July	*	*					
August	1.170	0.004	0.67	Aug	*	*	*				
September	1.088	0.004	0.72	Sept	*	*	*	*			
October	1.043	0.004	0.75	Oct	*	*	*	*	*		
November	1.025	0.004	0.76	Nov	*	*	*	*	*		
December	1.009	0.005	0.97	Dec	*	*	*	*	*	*	
Hardwood Stand					A						
Antenna	1.130	0.002	0.35	Antenna							
Control	1.140	0.002	0.34	Control	*						

a/ mean of transformed data
b/ estimated shift in the sample mean which would be detected 95 percent of the time ($\alpha = .05$), calculated as $t_{.05,n}$*S.E./Mean, and expressed as a percentage of the sample mean
c/ $\alpha = .05$, Tukey's H.S.D.

statistically detected. Year by site interactions were highly significant for both the plantations and hardwood stands, but did not affect the results of multiple comparisons.

Figures 15 and 16 present comparisons of monthly dry matter mass loss progress during the 1988-89 study on the plantation and hardwood stand subunits, respectively. Means representing the raw (untransformed) data are plotted between bars depicting their associated 95 percent confidence intervals. As with the individual pine fascicle samples, the general similarity among plantation and hardwood stand subunits is encouraging, and suggests that ANACOV may explain the differences detected by ANOVA. The significant differences detected between plantation subunits by ANOVA would be difficult to anticipate from the figures alone.

Figure 17 presents comparisons of monthly dry matter mass loss progress during the 1984-85 through 1988-89 studies on the ground unit plantation. Again, means are plotted between bars depicting their associated 95 percent confidence intervals. Figures 18 through 21 present corresponding comparisons for the antenna and control unit plantations and for the antenna and control unit hardwood stands, respectively. Again, the significant differences detected by ANOVA are small, suggesting that ANACOV may explain them.

Bulk Oak Leaf Litter

Tables 32 - 35 and 36 - 39 present the results of ANOVA for the plantation and hardwood stand subunits, respectively. Bulk oak leaf samples decomposed faster in the ground and antenna plantations than in the control plantation. ANOVA detected no difference in the rate of decomposition between the two hardwood stands. Comparing years in plantations, 1989 samples decomposed fastest, and 1986 and 1987 samples decomposed slowest (n.s.d., $\alpha = 0.05$); samples also decomposed similarly in 1985 and 1988. In the hardwood stands, 1989 samples decomposed fastest and 1986 samples slowest; 1987 and 1988 decomposition rates were similar. Significant monthly progress occurred both in the plantations and in the hardwood stands. Detectable differences were very low, below 1 percent for yearly and subunit mean values, and below 1.5 percent for monthly mean values. The year by site interaction was barely significant ($p = 0.0349$) for the plantation analysis, but highly significant for the hardwood stand analysis. Nevertheless, the results of multiple comparisons were not affected in either analysis.

Figures 22 and 23 present comparisons of monthly dry matter mass loss progress during the 1988-89 study on the plantation and hardwood stand subunits, respectively. Means representing the raw data are plotted between bars depicting their associated 95 percent confidence intervals. As with the bulk pine samples, the similarity in bulk oak sample decomposition among plantation and hardwood stand subunits is encouraging; the significant differences detected by ANOVA would be hard to anticipate from the figures alone.

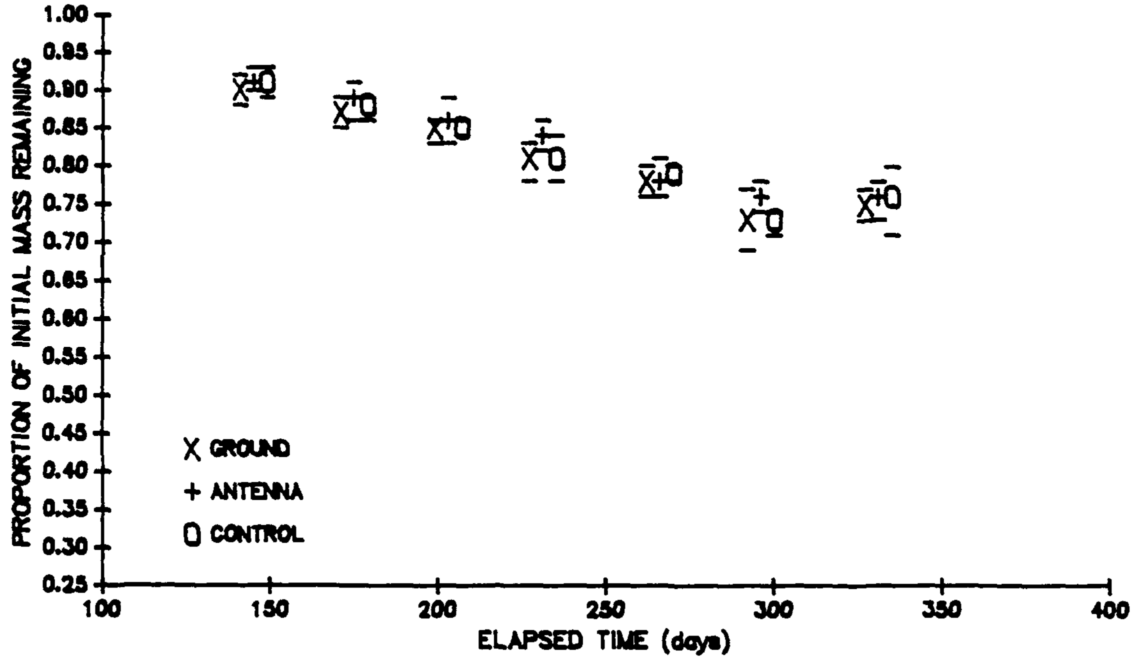


FIGURE 15. Proportion (X) of initial dry matter mass remaining for bulk pine needle samples retrieved from the three plantation subunits during the 1988–1989 experiment.

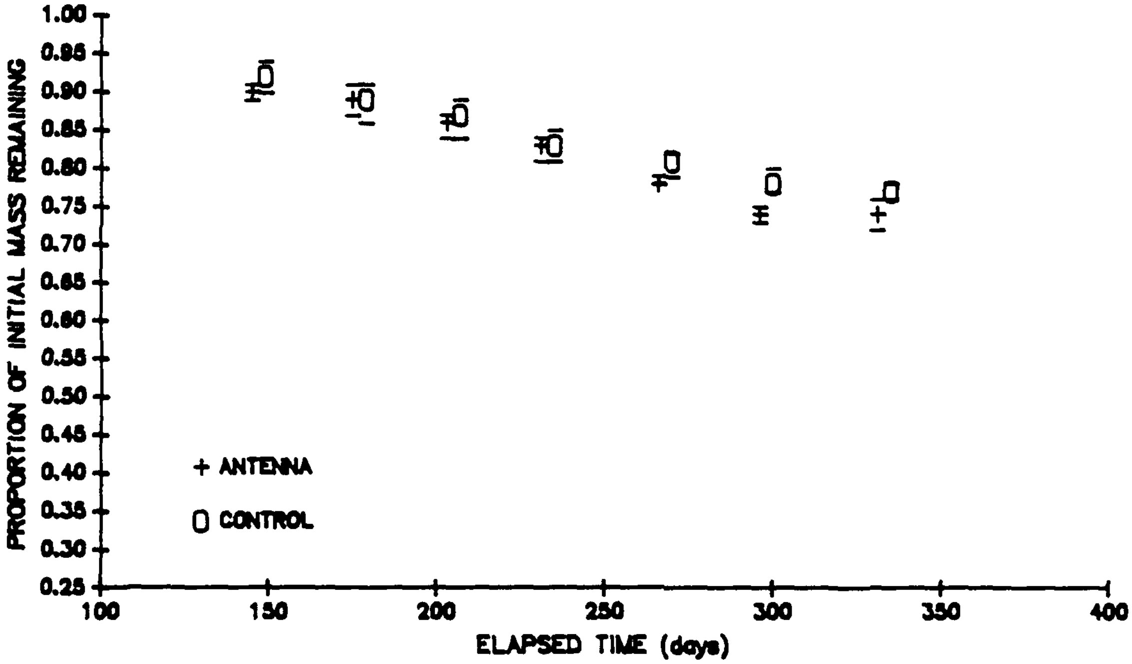


FIGURE 16. Proportion (X) of initial dry matter mass remaining for bulk pine needle samples retrieved from the two hardwood stand subunits during the 1988–1989 experiment.

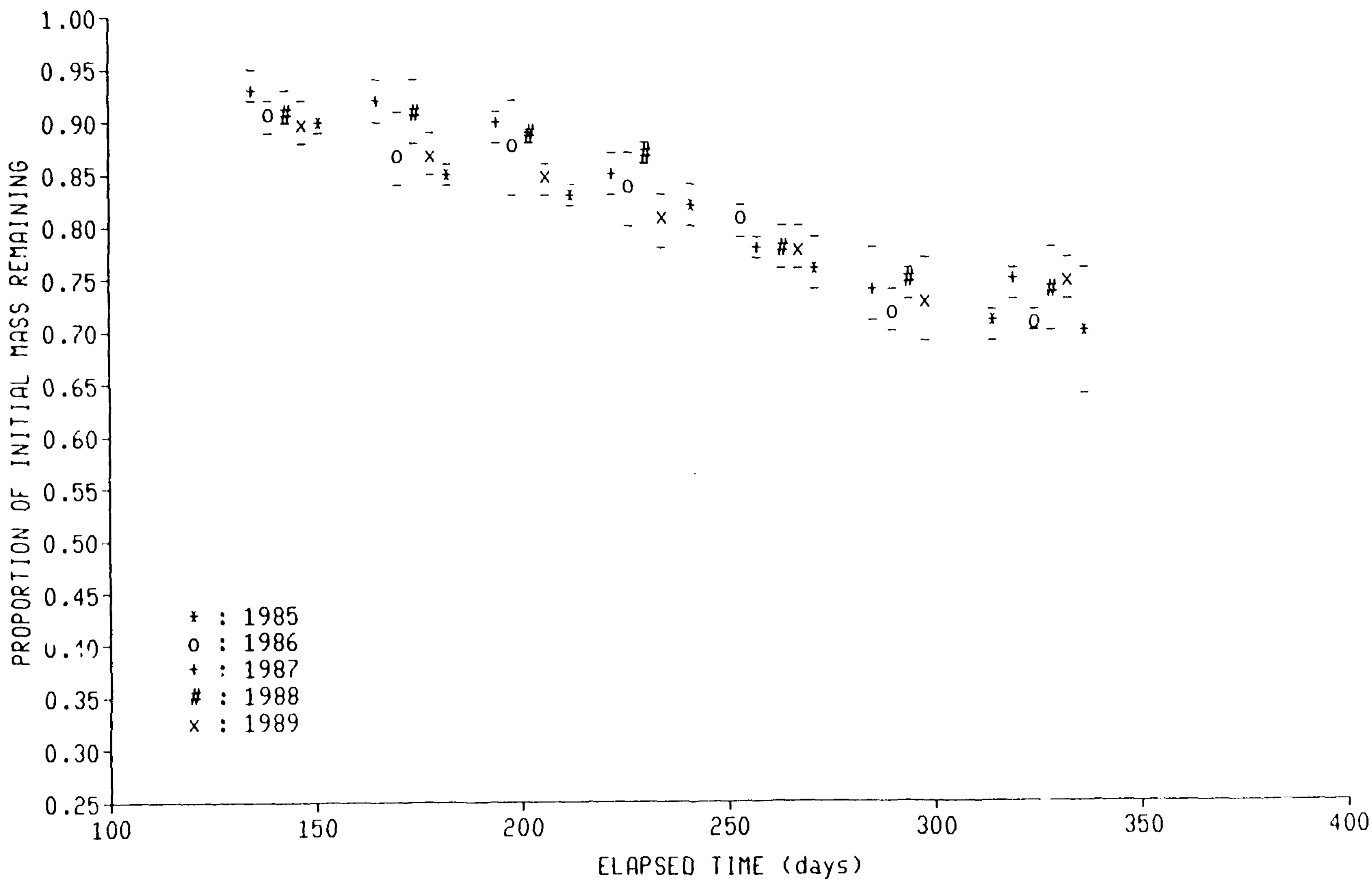


Figure 17. Proportion (X) of initial dry matter mass remaining for bulk pine needle samples retrieved from the ground unit plantation during the five consecutive annual experiments completed to date.

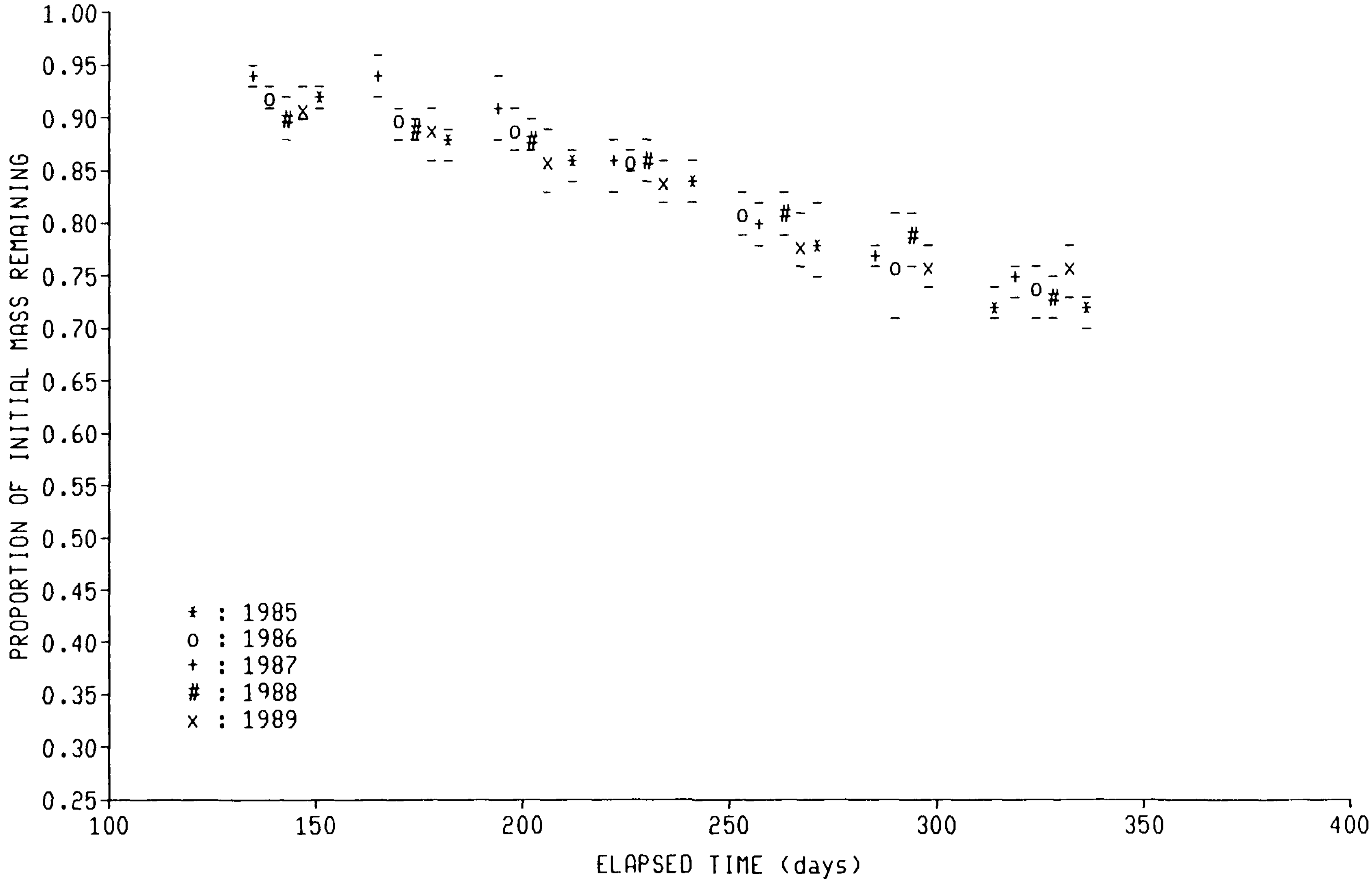


Figure 18. Proportion (X) of initial dry matter mass remaining for bulk pine needle samples retrieved from the antenna unit plantation during the five consecutive annual experiments completed to date.

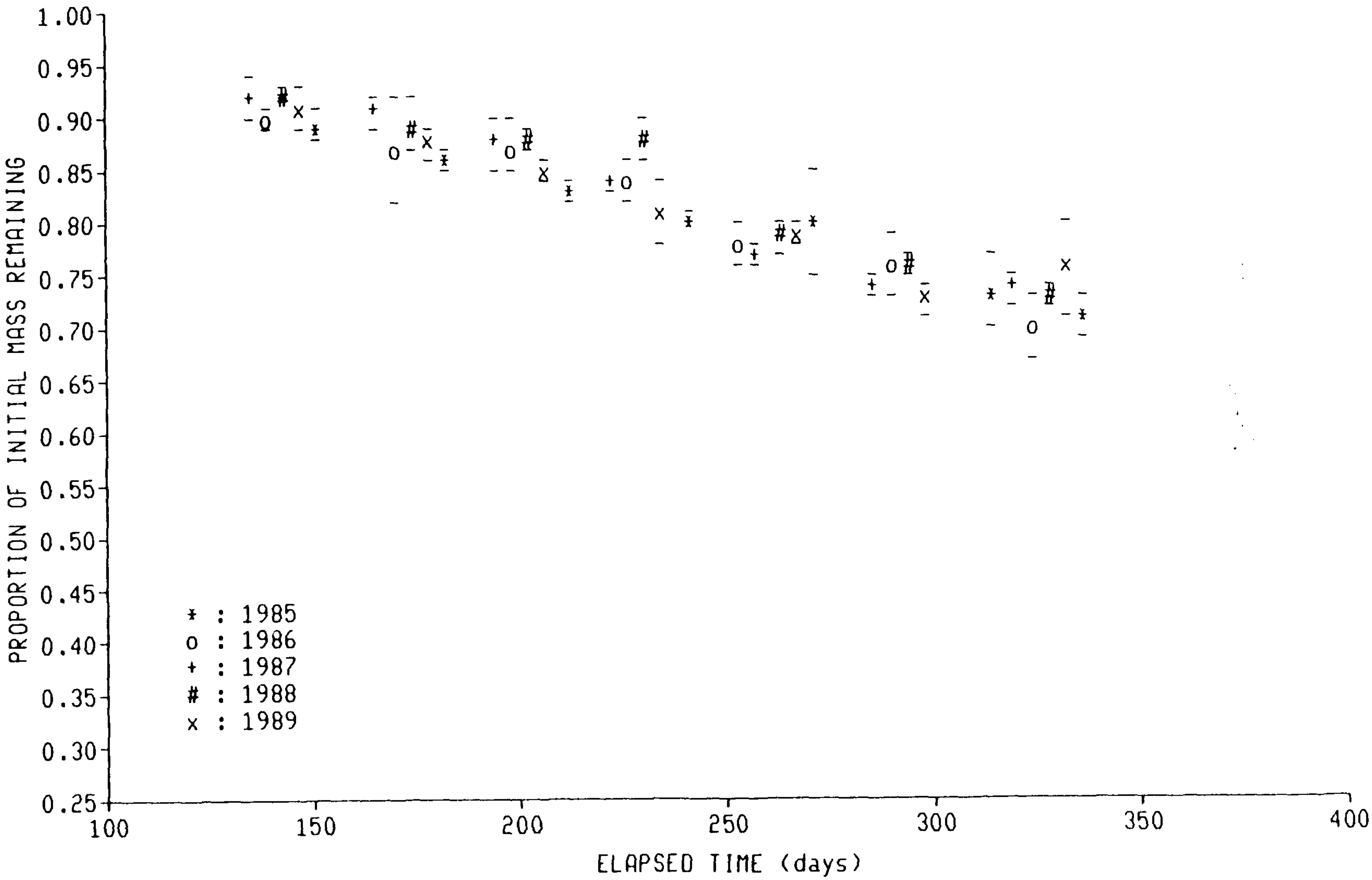


Figure 19. Proportion (X) of initial dry matter mass remaining for bulk pine needle samples retrieved from the control unit plantation during the five consecutive annual experiments completed to date.

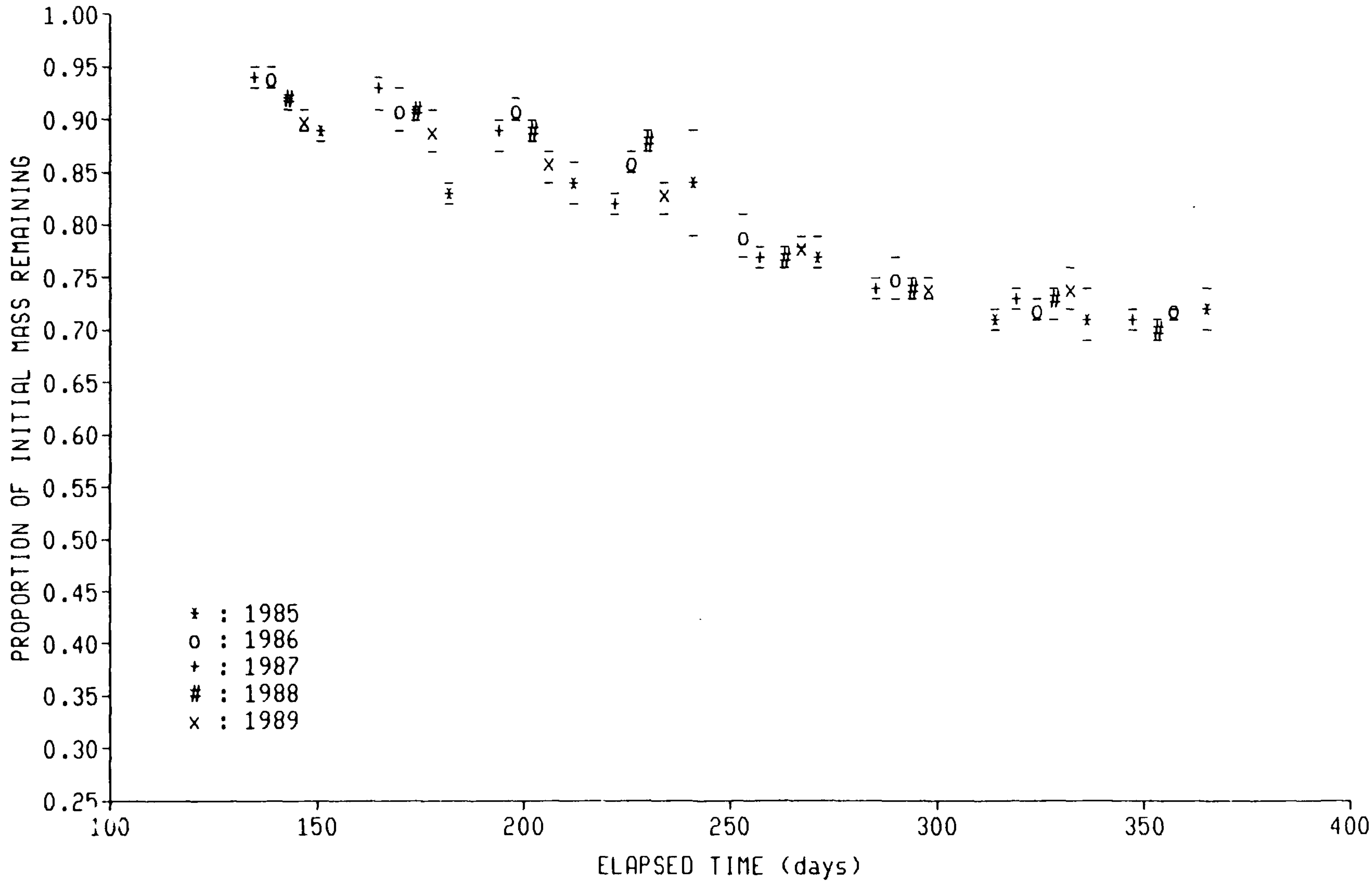


Figure 20. Proportion (X) of initial dry matter mass remaining for bulk pine needle samples retrieved from the antenna unit hardwood stand during the five consecutive annual experiments completed to date.

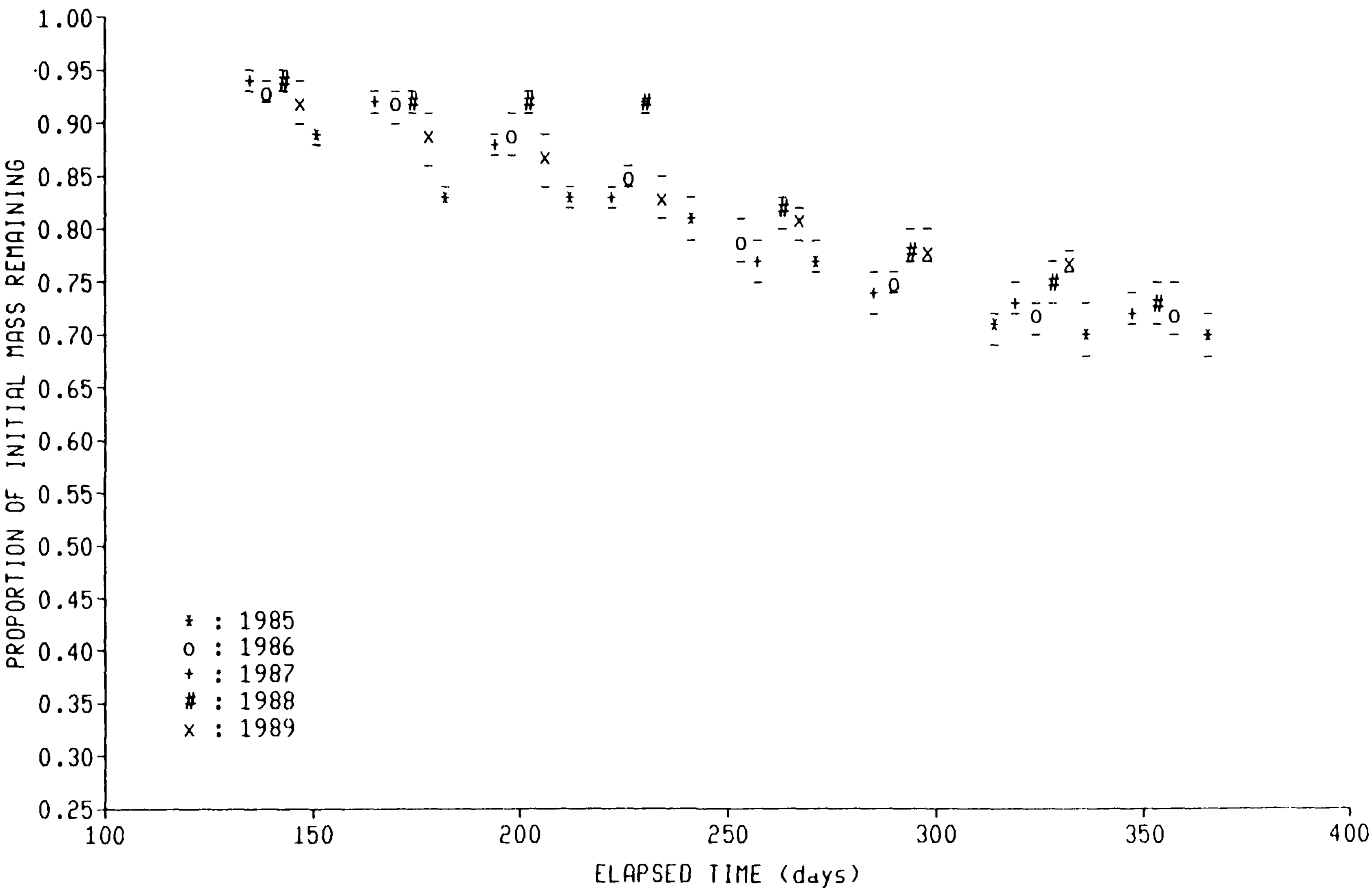


Figure 21. Proportion (X) of initial dry matter mass remaining for bulk pine needle samples retrieved from the control unit hardwood stand during the five consecutive annual experiments completed to date.

Table 32. ANOVA table for detection of differences in dry matter mass loss (arcsin square root of the proportion of initial mass remaining) from **bulk oak** leaf samples in the three **plantation** subunits, by year, sampling date, and subunit, and without the use of covariates.

Source of Variation	df	SS	Type III SS	F	Signif. of F	r^2
Model	12	7.85		237.47	0.0000	0.82
Year	4		0.30	26.90	0.0001	
Month	6		7.50	453.78	0.0000	
Plantation	2		0.05	9.31	0.0001	
Error	613	1.69				
Corrected Total	625	9.54				

Table 33. Adjusted means, standard errors, detectable differences, and significantly different pairs of means, based on the model analyzed in Table 32.

Source of Variation	Adjusted Mean[a]	Standard Error	Detectable Difference[b]	Significant Differences[c]						
Year					5	6	7	8		
1985	1.132	0.005	0.87	1985						
1986	1.171	0.005	0.84	1986	*					
1987	1.160	0.005	0.84	1987	*					
1988	1.144	0.005	0.86	1988		*	*			
1989	1.109	0.005	0.88	1989	*	*	*	*		
Month					1	2	3	4	5	6
May	1.304	0.006	0.90	May						
June	1.251	0.006	0.94	June	*					
July	1.205	0.006	0.98	July	*	*				
August	1.151	0.006	1.02	Aug	*	*	*			
September	1.078	0.006	1.09	Sept	*	*	*	*		
October	1.024	0.006	1.15	Oct	*	*	*	*	*	
November	0.987	0.006	1.19	Nov	*	*	*	*	*	*
Plantation					G	A	C			
Ground	1.134	0.004	0.69	Ground						
Antenna	1.140	0.004	0.69	Antenna						
Control	1.155	0.004	0.68	Control	*	*				

a/ mean of transformed data

b/ estimated shift in the sample mean which would be detected 95 percent of the time (α = .05), calculated as $t_{.05,n}$*S.E./Mean, and expressed as a percentage of the sample mean

c/ α = .05, Tukey's H.S.D.

Table 34. ANOVA table (including year * plantation interaction) for detection of differences in dry matter mass loss (arcsin square root of the proportion of initial mass remaining) from **bulk oak** leaf samples in the three **plantation** subunits, by year, sampling date, and subunit, and without the use of covariates.

Source of Variation	df	SS	Type III SS	F	Signif. of F	r^2
Model	20	7.89		145.34	0.0000	0.83
Year	4		0.30	27.40	0.0001	
Month	6		7.50	460.15	0.0000	
Plantation	2		0.05	9.35	0.0001	
Year*Plantation	8		0.05	2.09	0.0349	
Error	605	1.64				
Corrected Total	625	9.54				

Table 35. Adjusted means, standard errors, detectable differences, and significantly different pairs of means, based on the model analyzed in Table 34.

Source of Variation	Adjusted Mean[a]	Standard Error	Detectable Difference[b]	Significant Differences[c]						
Year					5	6	7	8		
1985	1.132	0.005	0.87	1985						
1986	1.171	0.005	0.84	1986	*					
1987	1.160	0.005	0.84	1987	*					
1988	1.144	0.005	0.86	1988		*	*			
1989	1.109	0.005	0.88	1989	*	*	*	*		
Month					1	2	3	4	5	6
May	1.304	0.005	0.75	May						
June	1.251	0.005	0.78	June	*					
July	1.205	0.005	0.81	July	*	*				
August	1.151	0.005	0.85	Aug	*	*	*			
September	1.078	0.005	0.91	Sept	*	*	*	*		
October	1.024	0.006	1.15	Oct	*	*	*	*	*	
November	0.987	0.006	1.19	Nov	*	*	*	*	*	*
Plantation						G	A	C		
Ground	1.134	0.004	0.69	Ground						
Antenna	1.140	0.004	0.69	Antenna						
Control	1.155	0.004	0.68	Control		*	*			

a/ mean of transformed data
b/ estimated shift in the sample mean which would be detected 95 percent of the time (α = .05), calculated as $t_{.05,n}$*S.E./Mean, and expressed as a percentage of the sample mean
c/ α = .05, Tukey's H.S.D.

Table 36. ANOVA table for detection of differences in dry matter mass loss (arcsin square root of the proportion of initial mass remaining) from **bulk oak** leaf samples in the two **hardwood stand** subunits, by year, sampling date, and subunit, and without the use of covariates.

Source of Variation	df	SS	Type III SS	F	Signif. of F	r^2
Model	12	7.51		271.49	0.0000	0.88
Year	4		0.50	54.50	0.0001	
Month	7		7.18	444.82	0.0000	
Hardwood Stand	1		0.00	0.28	0.5960	
Error	454	1.05				
Corrected Total	466	8.56				

Table 37. Adjusted means, standard errors, detectable differences, and significantly different pairs of means, based on the model analyzed in Table 36.

Source of Variation	Adjusted Mean[a]	Standard Error	Detectable Difference[b]	Significant Differences[c]							
Year					5	6	7	8			
1985	1.131	0.005	0.87	1985							
1986	1.199	0.005	0.82	1986	*						
1987	1.169	0.005	0.84	1987	*	*					
1988	1.174	0.005	0.83	1988	*	*					
1989	1.104	0.005	0.89	1989	*	*	*	*			
Month					1	2	3	4	5	6	7
May	1.324	0.006	1.03	May							
June	1.298	0.006	1.05	June	*						
July	1.258	0.006	1.07	July	*	*					
August	1.209	0.006	1.12	Aug	*	*	*				
September	1.116	0.006	1.21	Sept	*	*	*	*			
October	1.043	0.006	1.31	Oct	*	*	*	*	*		
November	1.019	0.006	1.35	Nov	*	*	*	*	*	*	
December	0.975	0.007	1.39	Dec	*	*	*	*	*	*	*
Hardwood Stand							A		C		
Antenna	1.154	0.003	0.51	Antenna							
Control	1.156	0.003	0.51	Control							

a/ mean of transformed data

b/ estimated shift in the sample mean which would be detected 95 percent of the time ($\alpha = .05$), calculated as $t_{.05,n}$*S.E./Mean, and expressed as a percentage of the sample mean

c/ $\alpha = .05$, Tukey's H.S.D.

Table 38. ANOVA table (including year * stand interaction) for detection of differences in dry matter mass loss (arcsin square root of the proportion of initial mass remaining) from **bulk oak** leaf samples in the two **hardwood stand** subunits, by year, sampling date, and subunit, and without the use of covariates.

Source of Variation	df	SS	Type III SS	F	Signif. of F	r^2
Model	16	7.63		232.86	0.0000	0.89
Year	4		0.50	61.30	0.0001	
Month	7		7.18	500.83	0.0000	
Hardwood Stand	1		0.00	0.55	0.4578	
Year * Stand	4		0.12	15.18	0.0001	
Error	450	0.92				
Corrected Total	466	8.56				

Table 39. Adjusted means, standard errors, detectable differences, and significantly different pairs of means, based on the model analyzed in Table 38.

Source of Variation	Adjusted Mean[a]	Standard Error	Detectable Difference[b]	Significant Differences[c]							
Year					5	6	7	8			
1985	1.131	0.005	0.87	1985							
1986	1.199	0.005	0.82	1986	*						
1987	1.169	0.005	0.84	1987	*	*					
1988	1.174	0.005	0.83	1988	*	*					
1989	1.104	0.005	0.89	1989	*	*	*	*			
Month					1	2	3	4	5	6	7
May	1.324	0.006	0.89	May							
June	1.298	0.006	0.91	June	*						
July	1.258	0.006	0.93	July	*	*					
August	1.209	0.006	0.97	Aug	*	*	*				
September	1.116	0.006	1.05	Sept	*	*	*	*			
October	1.043	0.006	1.13	Oct	*	*	*	*	*		
November	1.019	0.006	1.15	Nov	*	*	*	*	*	*	
December	0.974	0.007	1.41	Dec	*	*	*	*	*	*	*
Hardwood Stand					A	C					
Antenna	1.154	0.003	0.51	Antenna							
Control	1.157	0.003	0.51	Control							

a/ mean of transformed data

b/ estimated shift in the sample mean which would be detected 95 percent of the time (α = .05), calculated as $t_{.05,n}$*S.E./Mean, and expressed as a percentage of the sample mean

c/ α = .05, Tukey's H.S.D.

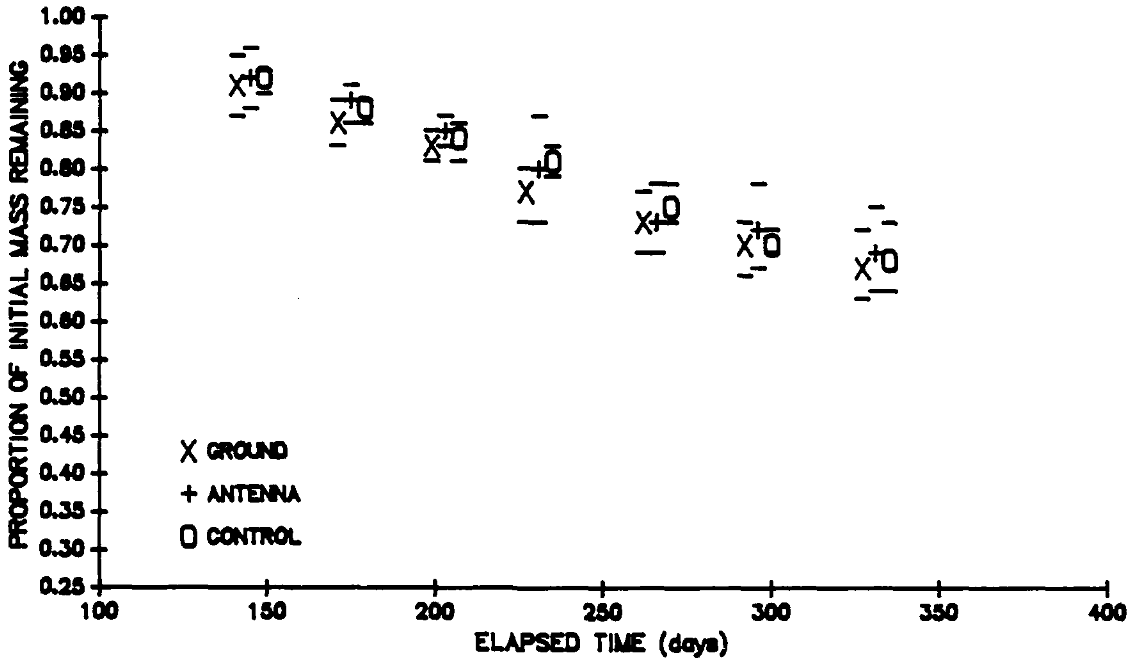


FIGURE 22. Proportion (X) of initial dry matter mass remaining for bulk oak leaf samples retrieved from the three plantation subunits during the 1988–1989 experiment.

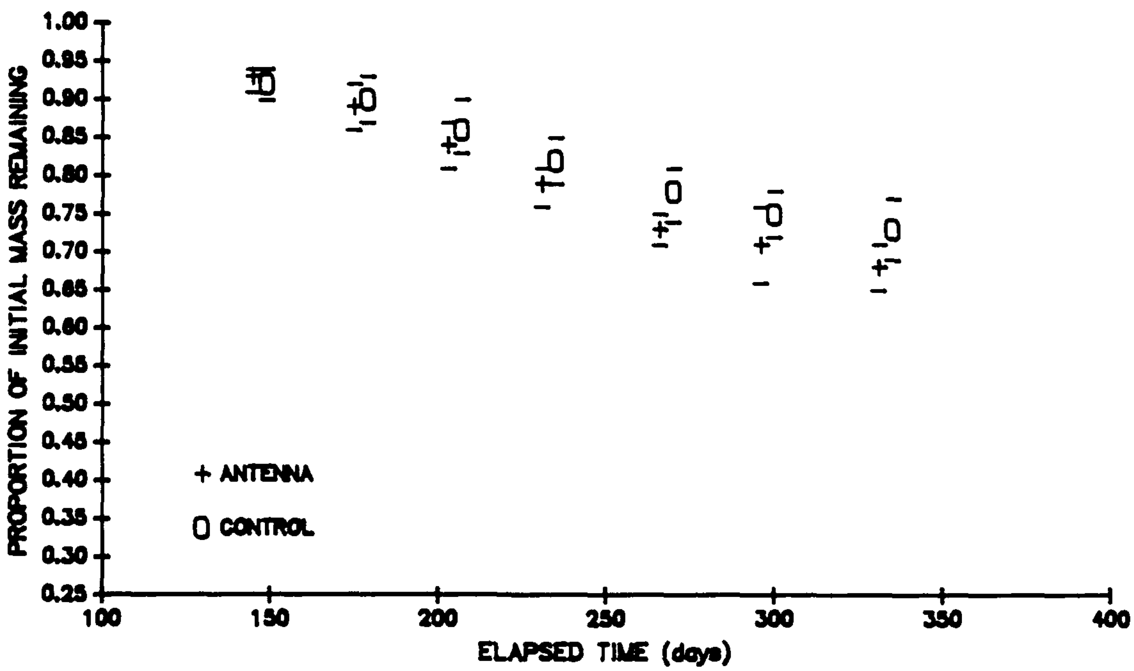


FIGURE 23. Proportion (X) of initial dry matter mass remaining for bulk oak leaf samples retrieved from the two hardwood stand subunits during the 1988–1989 experiment.

Figure 24 presents comparisons of monthly dry matter mass loss progress during the 1984-85 through 1988-89 studies on the ground unit plantation. Again, means are plotted between bars depicting their associated 95 percent confidence intervals. Figures 25 through 28 present corresponding comparisons for the antenna and control unit plantations and for the antenna and control unit hardwood stands, respectively. Again, the significant differences detected by ANOVA would be difficult to anticipate from the figures alone.

Bulk Maple Leaf Litter

Tables 40 - 43 and 44 - 47 present the results of ANOVA for the plantation and hardwood stand subunits, respectively. Bulk maple leaves decomposed faster in the ground and antenna plantations than in the control plantation. Samples also decomposed more rapidly in the antenna hardwood stand than in the control hardwood stand. Comparing years in the plantation and hardwood stand subunits alike, 1985 samples decomposed fastest, and 1989 samples decomposed slowest; 1986 and 1987 samples decomposed at similar rates. Significant monthly progress occurred in the plantation subunits, except in October (when the year by site interaction was omitted). Significant monthly progress occurred in the hardwood stands, except during June. Detectable differences were very low, nearly all well below 1.5 percent for yearly, monthly and subunit mean values. Though barely significant ($p = 0.0349$) for the plantation analysis, the year by site interaction was highly significant for the hardwood stand analysis, and had no effect on results of multiple comparisons in either analysis. Interestingly, however, the year by site interaction did have the effect of lowering a number of detectable differences in these models.

Figures 29 and 30 present comparisons of monthly progress in dry matter mass loss during the 1988-89 study on the plantation and hardwood stand subunits, respectively. Means representing the raw (untransformed) data are plotted between bars depicting their associated 95 percent confidence intervals. The bulk maple data tend to be slightly more variable than the bulk pine and bulk oak data. The similarity in bulk maple leaf decomposition among the plantation and hardwood stand subunits is encouraging.

Figure 31 presents monthly progress in dry matter mass loss during the 1984-85 through 1988-89 studies on the ground unit plantation. Again, means are plotted between bars depicting their associated 95 percent confidence intervals. Figures 32 through 35 present corresponding comparisons for the antenna and control unit plantations and for the antenna and control unit hardwood stands, respectively. Again, the greater variability in bulk maple sample decomposition than that observed for pine or oak is clearly depicted in these figures. The significantly faster decomposition during 1985 than during any subsequent year in both the plantation and hardwood stand subunits is readily apparent.

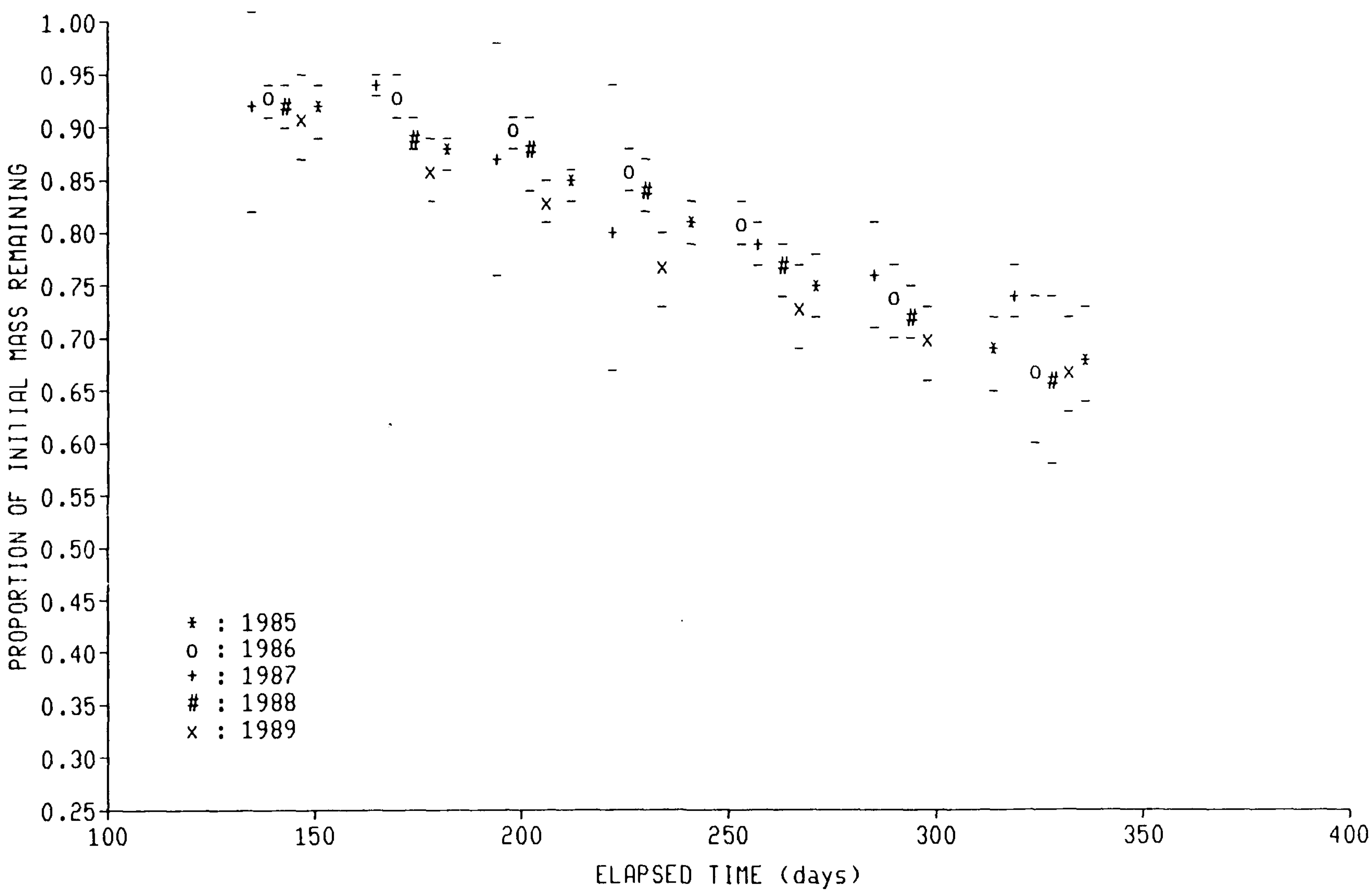


Figure 24. Proportion (X) of initial dry matter mass remaining for bulk oak leaf samples retrieved from the ground unit plantation during the five consecutive annual experiments completed to date.

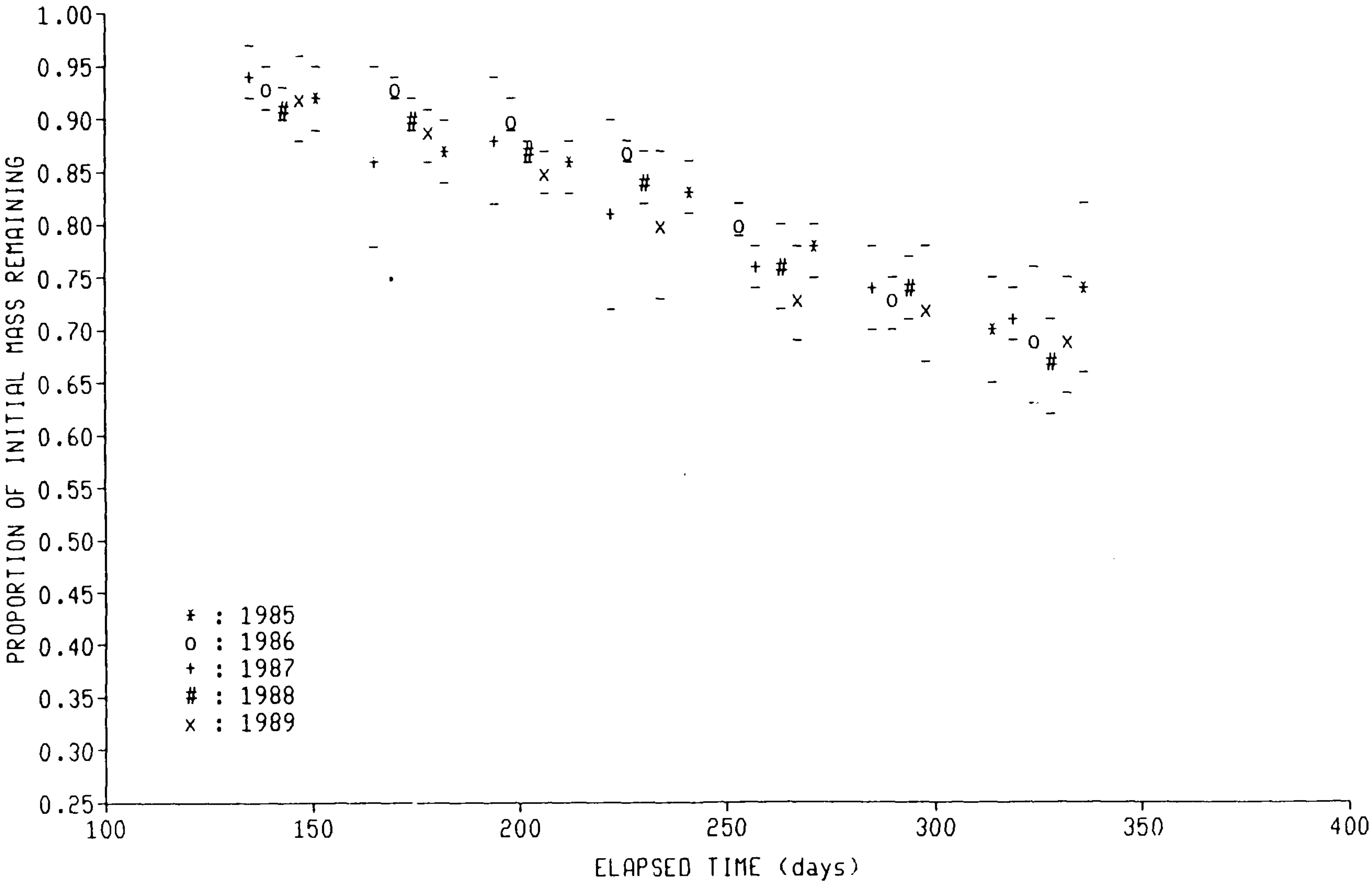


Figure 25. Proportion (X) of initial dry matter mass remaining for bulk oak leaf samples retrieved from the antenna unit plantation during the five consecutive annual experiments completed to date.

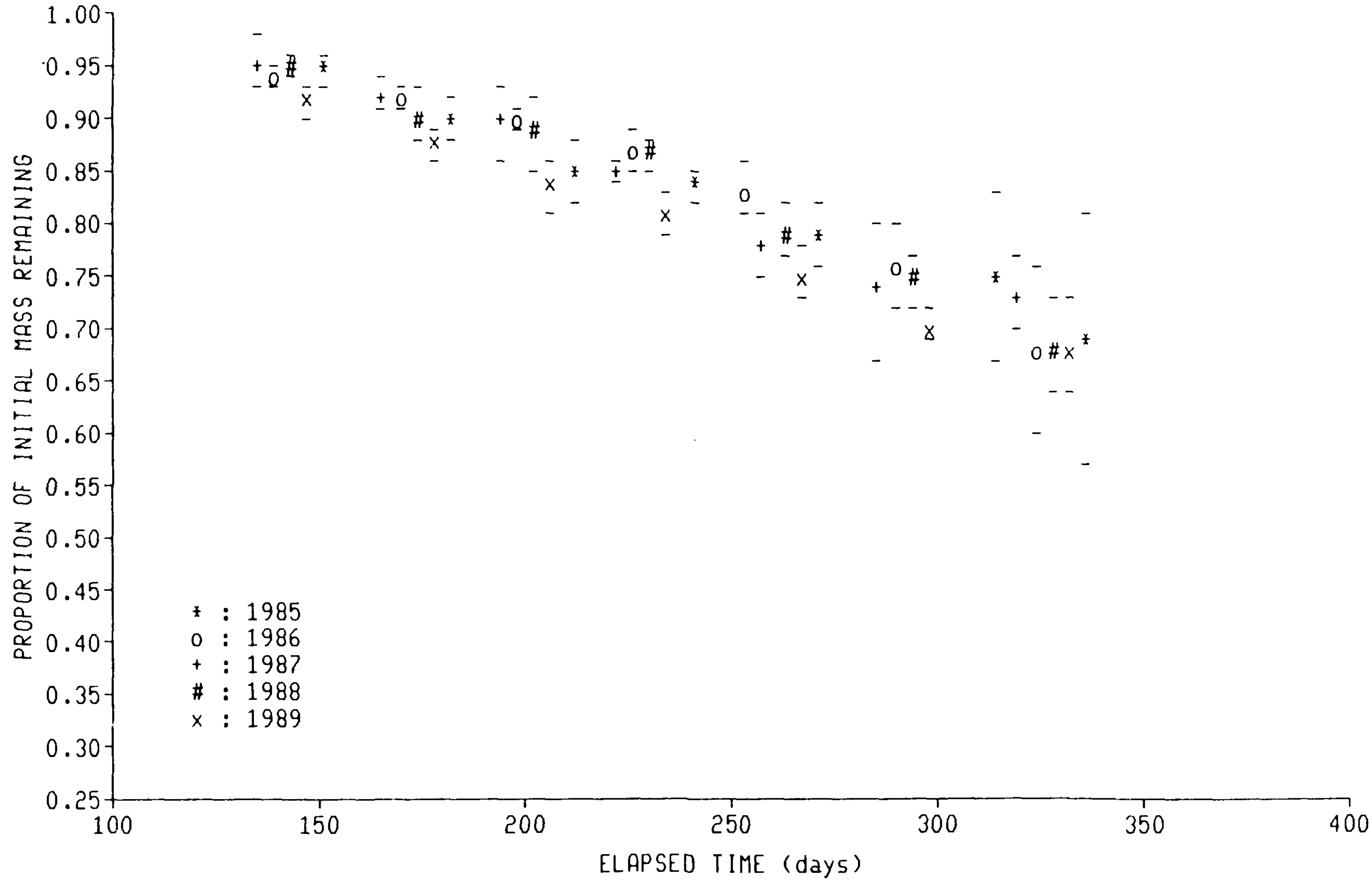


Figure 26. Proportion (X) of initial dry matter mass remaining for bulk oak leaf samples retrieved from the control unit plantation during the five consecutive annual experiments completed to date.

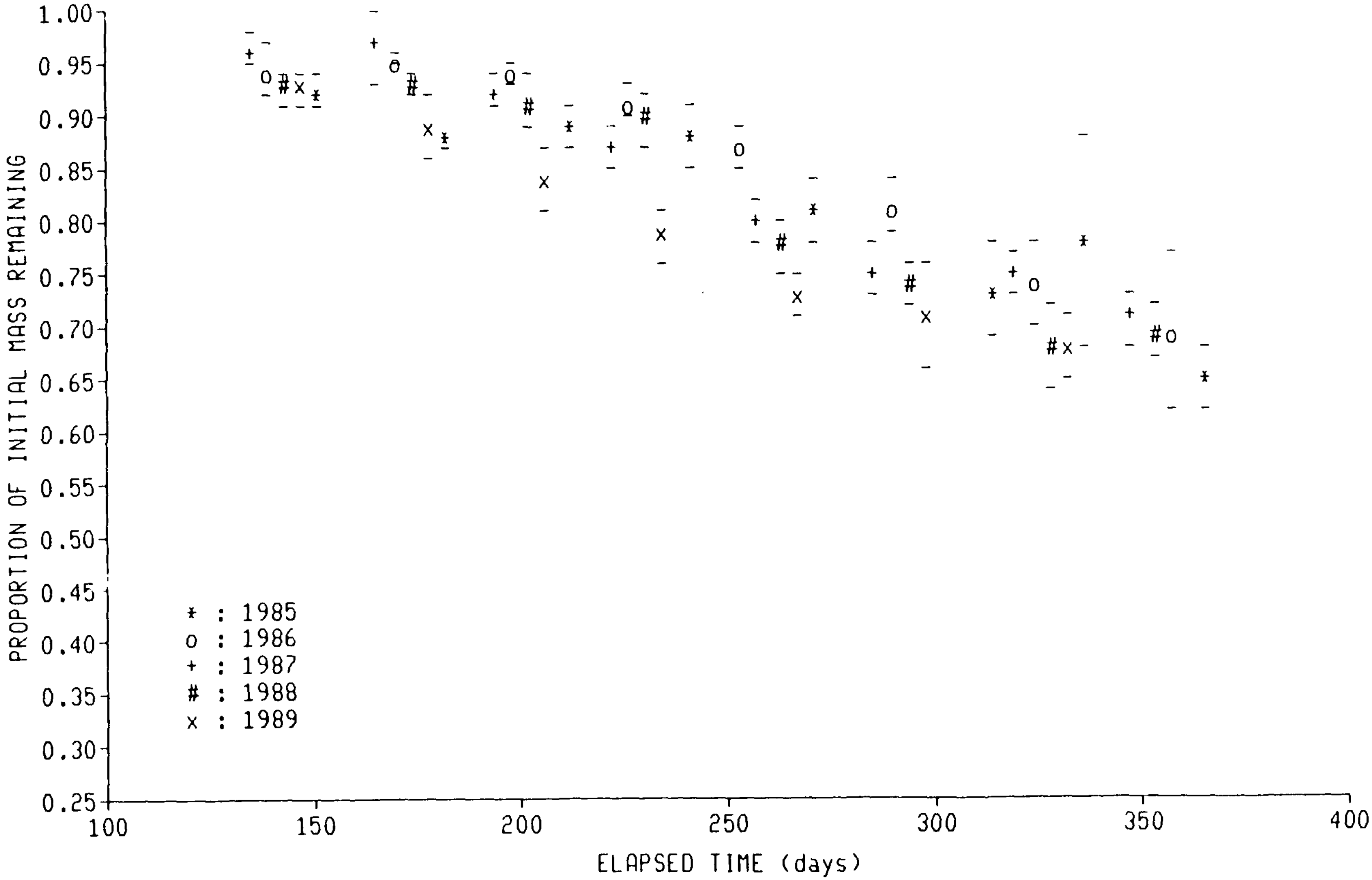


Figure 27. Proportion (X) of initial dry matter mass remaining for bulk oak leaf samples retrieved from the antenna unit hardwood stand during the five consecutive annual experiments completed to date.

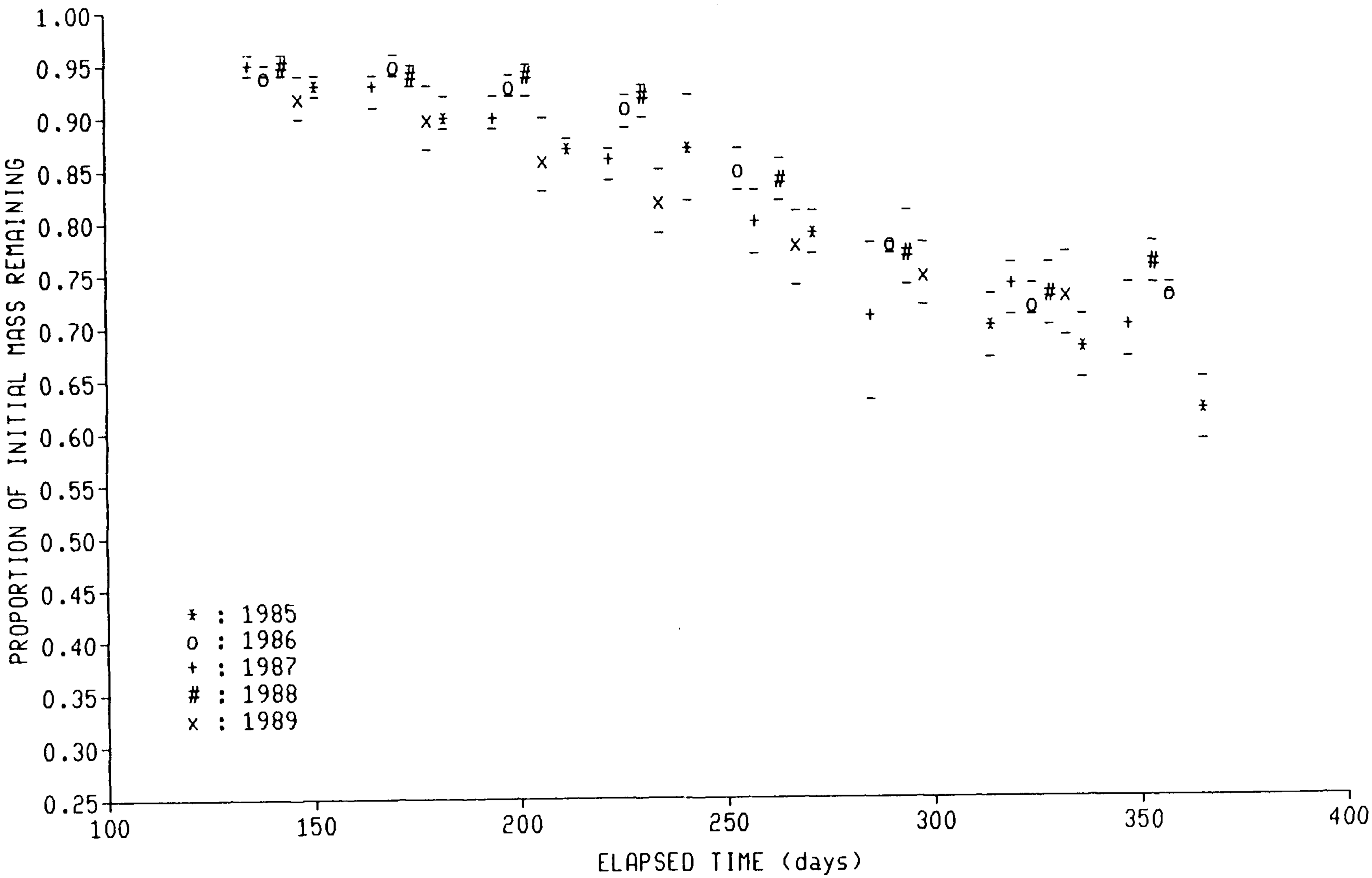


Figure 28. Proportion (X) of initial dry matter mass remaining for bulk oak leaf samples retrieved from the control unit hardwood stand during the five consecutive annual experiments completed to date.

Table 40. ANOVA table for detection of differences in dry matter mass loss (arcsin square root of the proportion of initial mass remaining) from **bulk maple** leaf samples in the three **plantation** subunits, by year, sampling date, and subunit, and without the use of covariates.

Source of Variation	df	SS	Type III SS	F	Signif. of F	r^2
Model	12	11.00		344.78	0.0000	0.87
Year	4		4.93	463.29	0.0000	
Month	6		5.92	371.01	0.0000	
Plantation	2		0.11	20.73	0.0001	
Error	611	1.62				
Corrected Total	623	12.62				

Table 41. Adjusted means, standard errors, detectable differences, and significantly different pairs of means, based on the model analyzed in Table 40.

Source of Variation	Adjusted Mean[a]	Standard Error	Detectable Difference[b]	Significant Differences[c]						
Year					5	6	7	8		
1985	0.829	0.005	1.18	1985						
1986	0.977	0.005	1.00	1986	*					
1987	0.985	0.005	0.99	1987	*					
1988	0.913	0.005	1.07	1988	*	*	*			
1989	1.098	0.005	0.89	1989	*	*	*	*		
Month					1	2	3	4	5	6
May	1.116	0.005	0.88	May						
June	1.054	0.005	0.93	June	*					
July	1.010	0.005	0.97	July	*	*				
August	0.959	0.005	1.02	Aug	*	*	*			
September	0.901	0.005	1.09	Sept	*	*	*	*		
October	0.850	0.005	1.15	Oct	*	*	*	*	*	
November	0.835	0.006	1.41	Nov	*	*	*	*	*	
Plantation						G	A	C		
Ground	0.949	0.004	0.83	Ground						
Antenna	0.954	0.004	0.82	Antenna						
Control	0.979	0.004	0.80	Control		*	*			

a/ mean of transformed data

b/ estimated shift in the sample mean which would be detected 95 percent of the time (α = .05), calculated as $t_{.05,n}$*S.E./Mean, and expressed as a percentage of the sample mean

c/ α = .05, Tukey's H.S.D.

Table 42. ANOVA table (including year * plantation interaction) for detection of differences in dry matter mass loss (arcsin square root of the proportion of initial mass remaining) from **bulk maple** leaf samples in the three **plantation** subunits, by year, sampling date, and subunit, and without the use of covariates.

Source of Variation	df	SS	Type III SS	F	Signif. of F	r^2
Model	20	7.89		145.34	0.0000	0.83
Year	4		0.30	27.40	0.0001	
Month	6		7.50	460.15	0.0000	
Plantation	2		0.05	9.35	0.0001	
Year*Plantation	8		0.05	2.09	0.0349	
Error	605	1.64				
Corrected Total	625	9.54				

Table 43. Adjusted means, standard errors, detectable differences, and significantly different pairs of means, based on the model analyzed in Table 42.

Source of Variation	Adjusted Mean[a]	Standard Error	Detectable Difference[b]	Significant Differences[c]						
Year					5	6	7	8		
1985	0.829	0.004	0.95	1985						
1986	0.977	0.005	1.00	1986	*					
1987	0.985	0.004	0.80	1987	*					
1988	0.913	0.004	0.86	1988	*	*	*			
1989	1.098	0.004	0.71	1989	*	*	*	*		
Month					1	2	3	4	5	6
May	1.116	0.005	0.88	May						
June	1.054	0.005	0.93	June	*					
July	1.010	0.005	0.97	July	*	*				
August	0.959	0.005	1.02	Aug	*	*	*			
September	0.901	0.005	1.09	Sept	*	*	*	*		
October	0.850	0.005	1.15	Oct	*	*	*	*	*	
November	0.835	0.005	1.17	Nov	*	*	*	*	*	*
Plantation						G	A	C		
Ground	0.949	0.003	0.62	Ground						
Antenna	0.954	0.003	0.62	Antenna						
Control	0.979	0.003	0.60	Control		*	*			

a/ mean of transformed data

b/ estimated shift in the sample mean which would be detected 95 percent of the time (α = .05), calculated as $t_{.05,n}$*S.E./Mean, and expressed as a percentage of the sample mean

c/ α = .05, Tukey's H.S.D.

Table 44. ANOVA table for detection of differences in dry matter mass loss (arcsin square root of the proportion of initial mass remaining) from **bulk maple** leaf samples in the two **hardwood stand** subunits, by year, sampling date, and subunit, and without the use of covariates.

Source of Variation	df	SS	Type III SS	F	Signif. of F	r^2
Model	12	7.24		364.49	0.0000	0.91
Year	4		3.58	541.25	0.0000	
Month	7		3.16	272.64	0.0000	
Hardwood Stand	1		0.04	24.69	0.0001	
Error	454	0.75				
Corrected Total	466	7.99				

Table 45. Adjusted means, standard errors, detectable differences, and significantly different pairs of means, based on the model analyzed in Table 44.

Source of Variation	Adjusted Mean[a]	Standard Error	Detectable Difference[b]	Significant Differences[c]							
Year					5	6	7	8			
1985	0.890	0.004	0.88	1985							
1986	1.057	0.004	0.74	1986	*						
1987	1.064	0.004	0.74	1987	*						
1988	0.961	0.004	0.82	1988	*	*	*				
1989	1.148	0.005	0.85	1989	*	*	*	*			
Month					1	2	3	4	5	6	7
May	1.147	0.005	0.85	May							
June	1.105	0.005	0.89	June	*						
July	1.098	0.005	0.89	July	*						
August	1.052	0.005	0.93	Aug	*	*	*				
September	0.999	0.005	0.98	Sept	*	*	*	*			
October	0.951	0.005	1.03	Oct	*	*	*	*	*		
November	0.934	0.005	1.05	Nov	*	*	*	*	*	*	
December	0.906	0.006	1.30	Dec	*	*	*	*	*	*	*
Hardwood Stand					A	C					
Antenna	1.015	0.003	0.58	Antenna							
Control	1.033	0.003	0.57	Control	*						

a/ mean of transformed data
b/ estimated shift in the sample mean which would be detected 95 percent of the time (α = .05), calculated as $t_{.05,n}$*S.E./Mean, and expressed as a percentage of the sample mean
c/ α = .05, Tukey's H.S.D.

Table 46. ANOVA table (including year * stand interaction) for detection of differences in dry matter mass loss (arcsin square root of the proportion of initial mass remaining) from **bulk maple** leaf samples in the two **hardwood stand** subunits, by year, sampling date, and subunit, and without the use of covariates.

Source of Variation	df	SS	Type III SS	F	Signif. of F	r^2
Model	16	7.32		308.16	0.0000	0.92
Year	4		3.59	603.98	0.0000	
Month	7		3.15	303.44	0.0000	
Hardwood Stand	1		0.04	29.23	0.0001	
Year * Stand	4		0.08	14.00	0.0001	
Error	450	0.67				
Corrected Total	466	7.99				

Table 47. Adjusted means, standard errors, detectable differences, and significantly different pairs of means, based on the model analyzed in Table 46.

Source of Variation	Adjusted Mean[a]	Standard Error	Detectable Difference[b]	Significant Differences[c]							
Year					5	6	7	8			
1985	0.890	0.004	0.88	1985							
1986	1.057	0.004	0.74	1986	*						
1987	1.064	0.004	0.74	1987	*						
1988	0.961	0.004	0.82	1988	*	*	*				
1989	1.148	0.004	0.68	1989	*	*	*	*			
Month					1	2	3	4	5	6	7
May	1.147	0.005	0.85	May							
June	1.105	0.005	0.89	June	*						
July	1.098	0.005	0.89	July	*						
August	1.052	0.005	0.93	Aug	*	*	*				
September	0.999	0.005	0.98	Sept	*	*	*	*			
October	0.951	0.005	1.03	Oct	*	*	*	*	*		
November	0.934	0.005	1.05	Nov	*	*	*	*	*	*	
December	0.906	0.006	1.30	Dec	*	*	*	*	*	*	*
Hardwood Stand					A	C					
Antenna	1.014	0.003	0.58	Antenna							
Control	1.034	0.003	0.57	Control	*						

a/ mean of transformed data

b/ estimated shift in the sample mean which would be detected 95 percent of the time (α = .05), calculated as $t_{.05,n}$*S.E./Mean, and expressed as a percentage of the sample mean

c/ α = .05, Tukey's H.S.D.

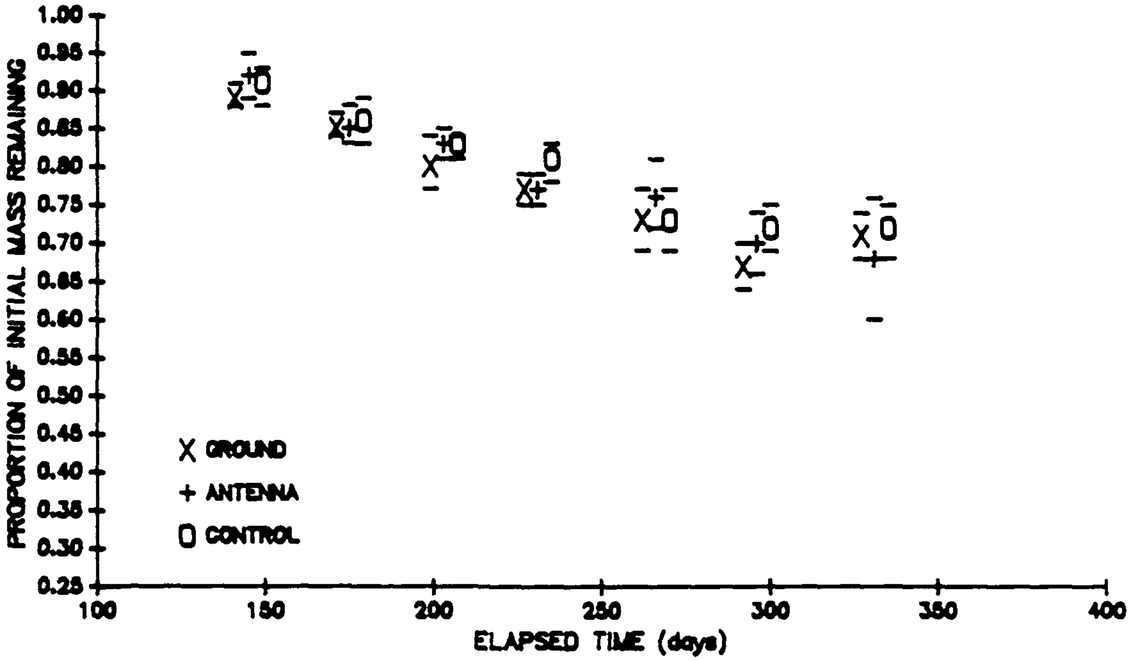


FIGURE 29. Proportion (X) of initial dry matter mass remaining for bulk maple leaf samples retrieved from the three plantation subunits during the 1988–1989 experiment.

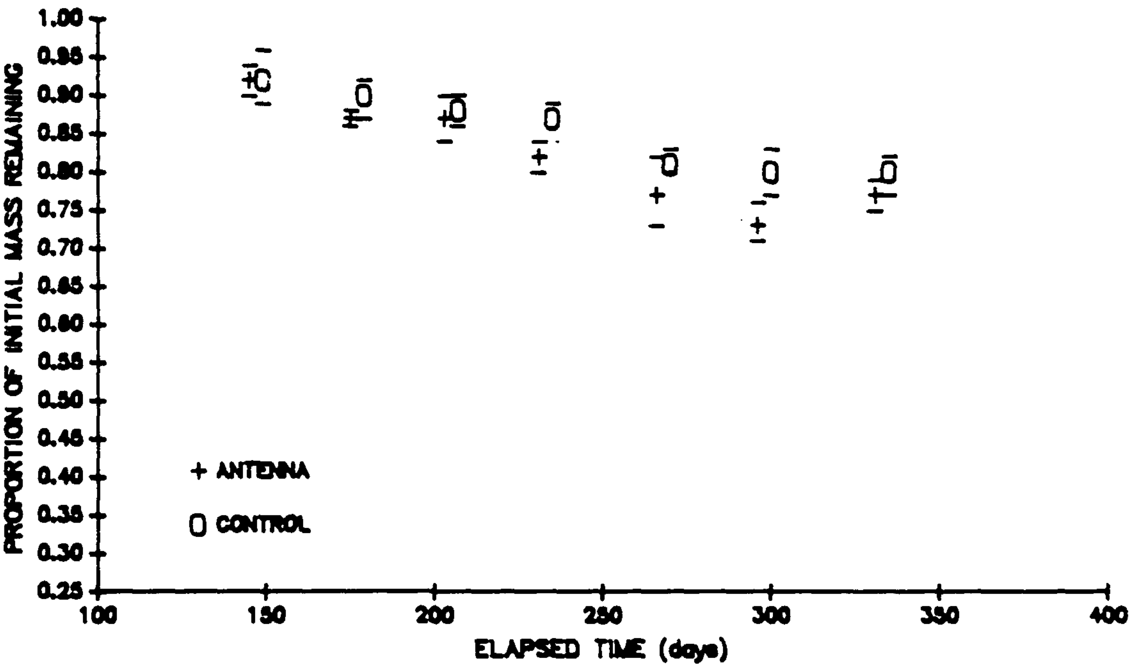


FIGURE 30. Proportion (X) of initial dry matter mass remaining for bulk maple leaf samples retrieved from the two hardwood stand subunits during the 1988–1989 experiment.

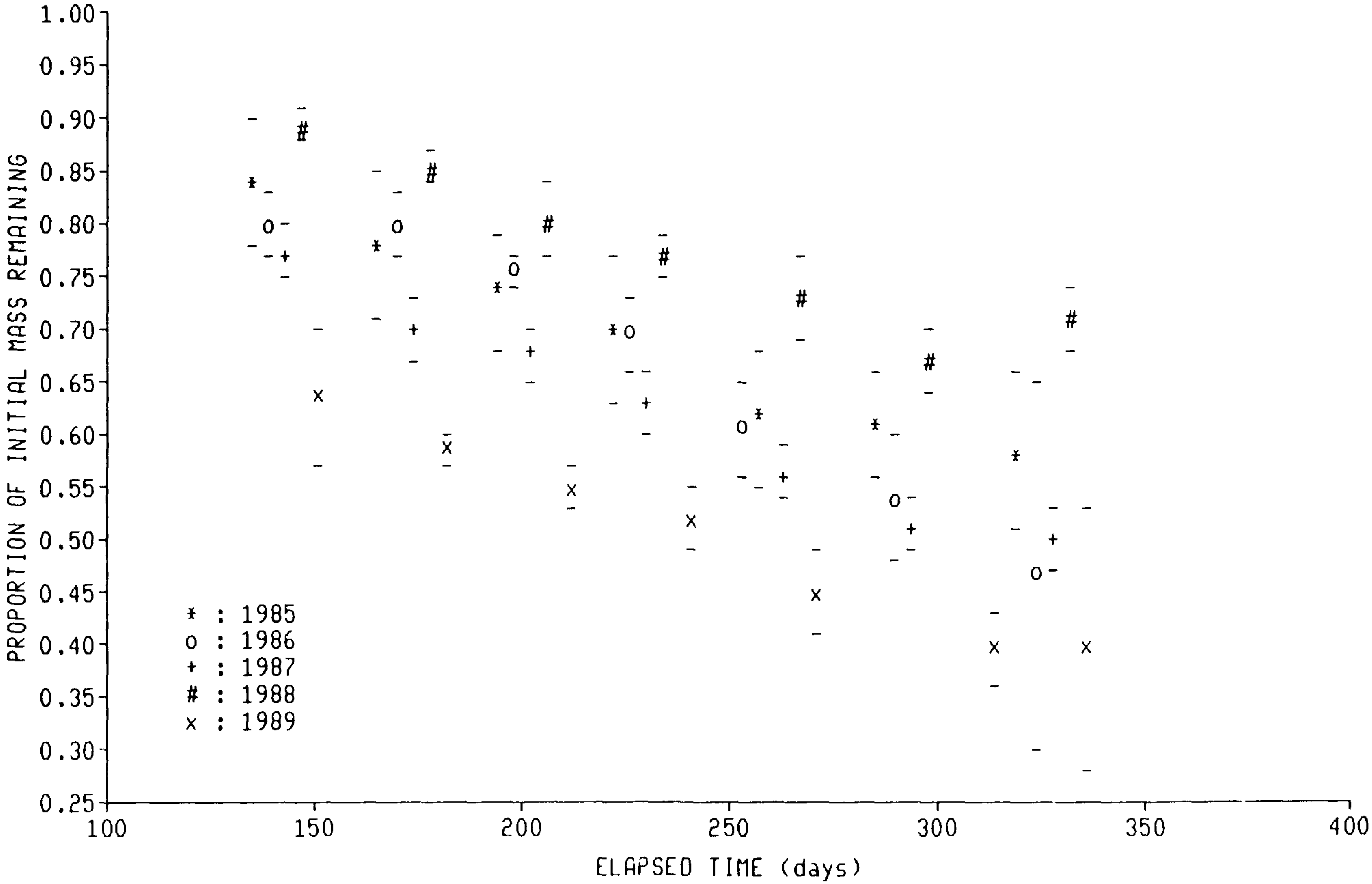


Figure 31. Proportion (X) of initial dry matter mass remaining for bulk maple leaf samples retrieved from the ground unit plantation during the five consecutive annual experiments completed to date.

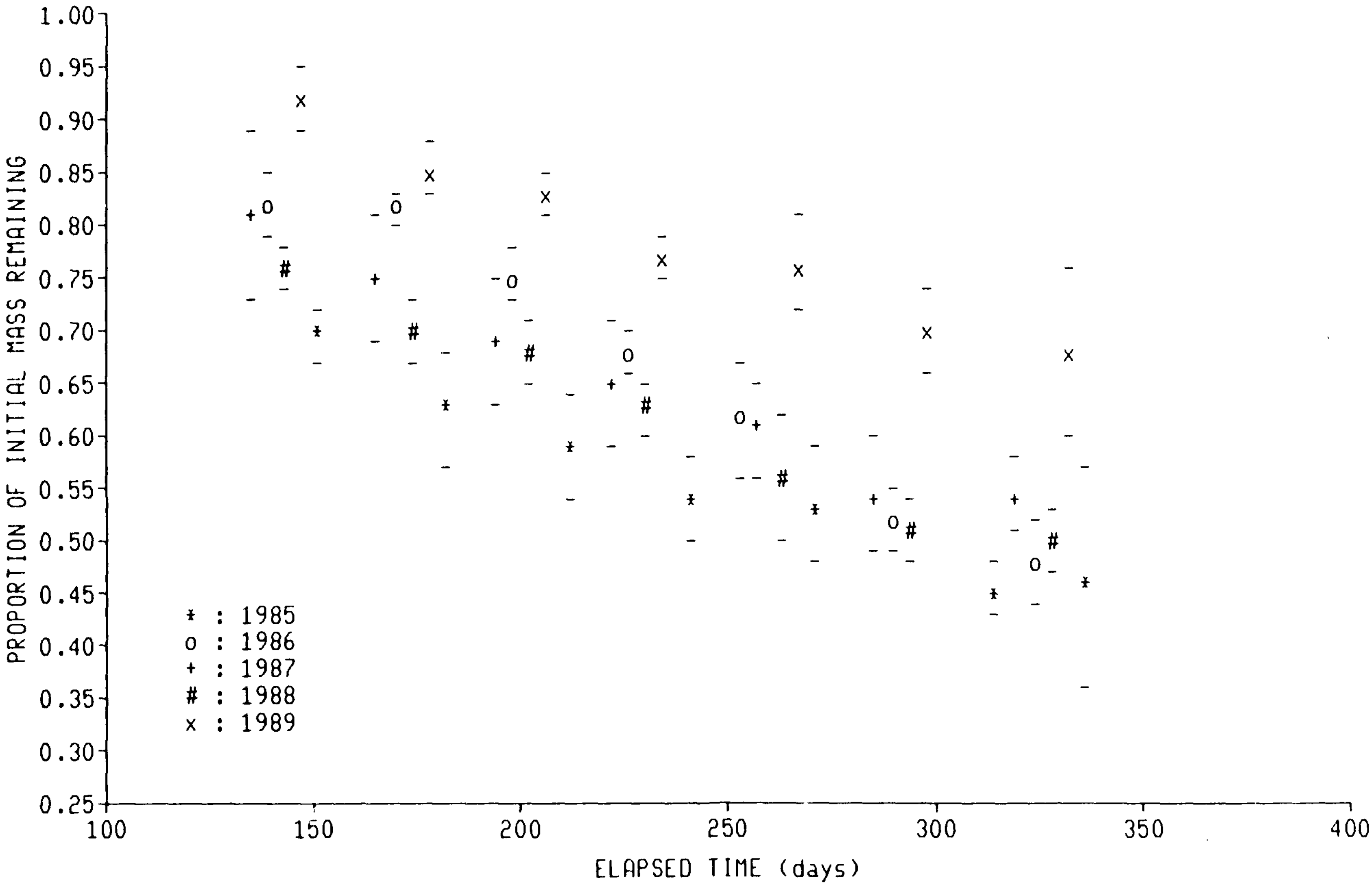


Figure 32. Proportion (X) of initial dry matter mass remaining for bulk maple leaf samples retrieved from the antenna unit plantation during the five consecutive annual experiments completed to date.

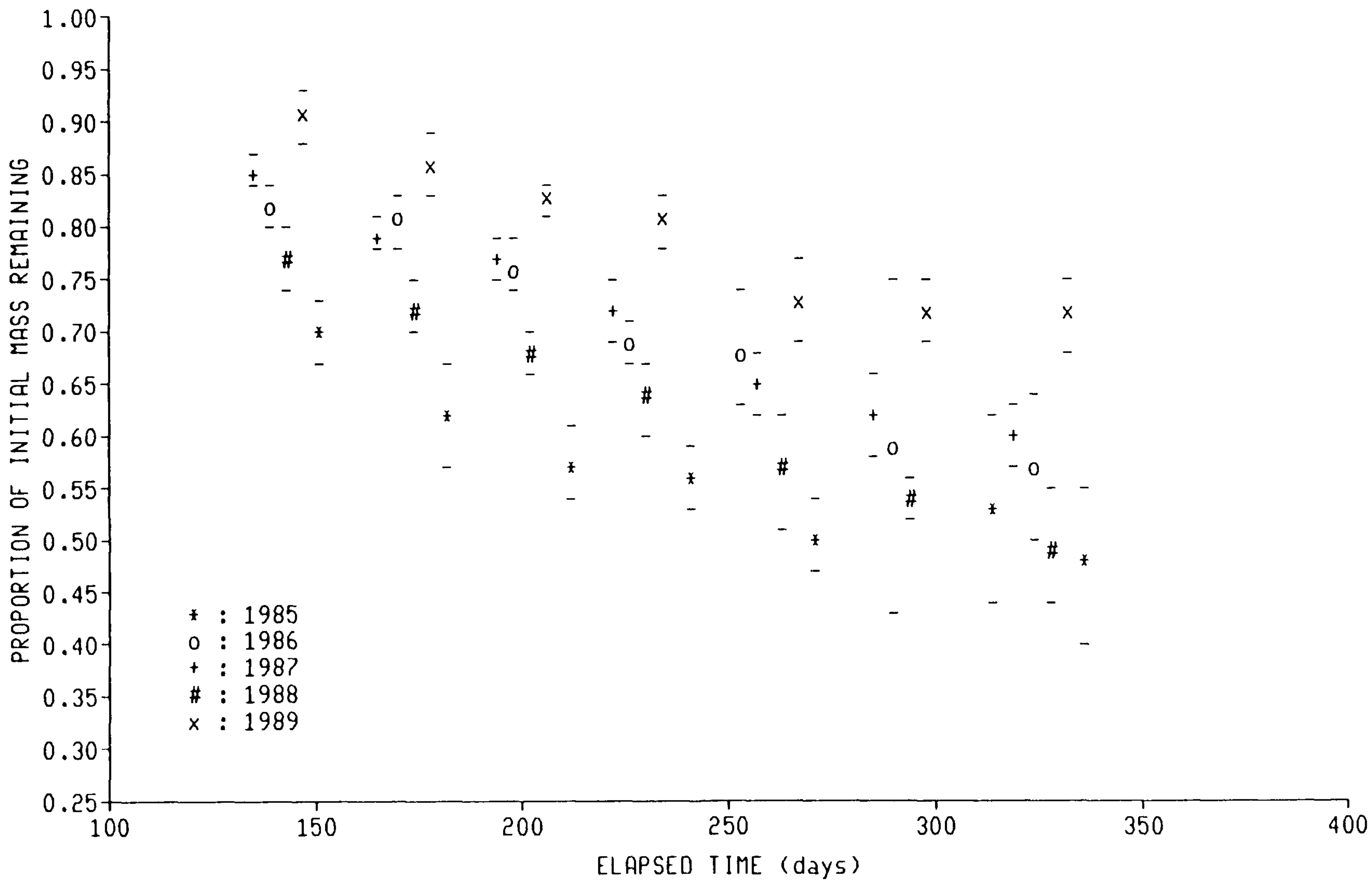


Figure 33. Proportion (X) of initial dry matter mass remaining for bulk maple leaf samples retrieved from the control unit plantation during the five consecutive annual experiments completed to date.

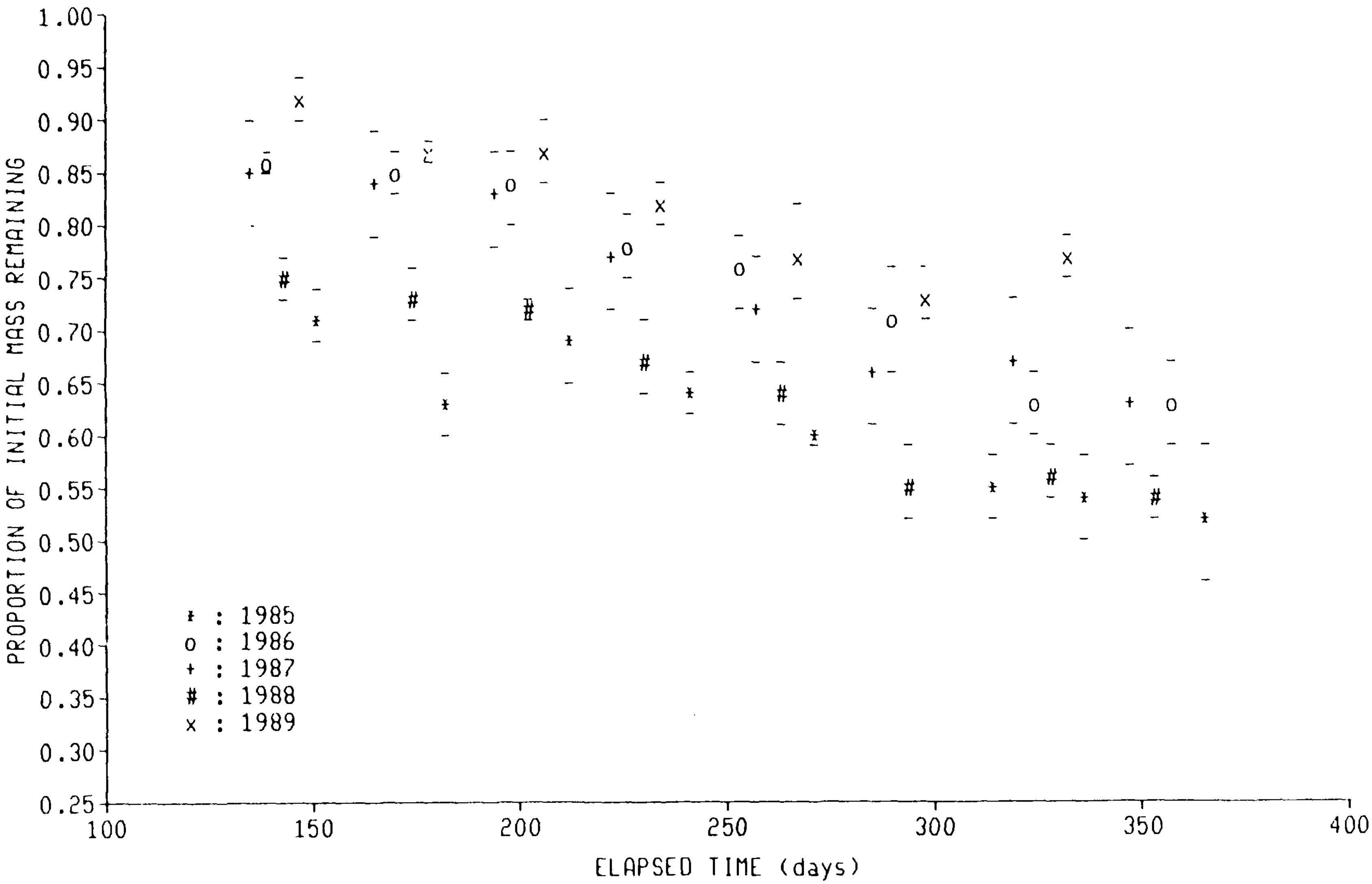


Figure 34. Proportion (X) of initial dry matter mass remaining for bulk maple leaf samples retrieved from the antenna unit hardwood stand during the five consecutive annual experiments completed to date.

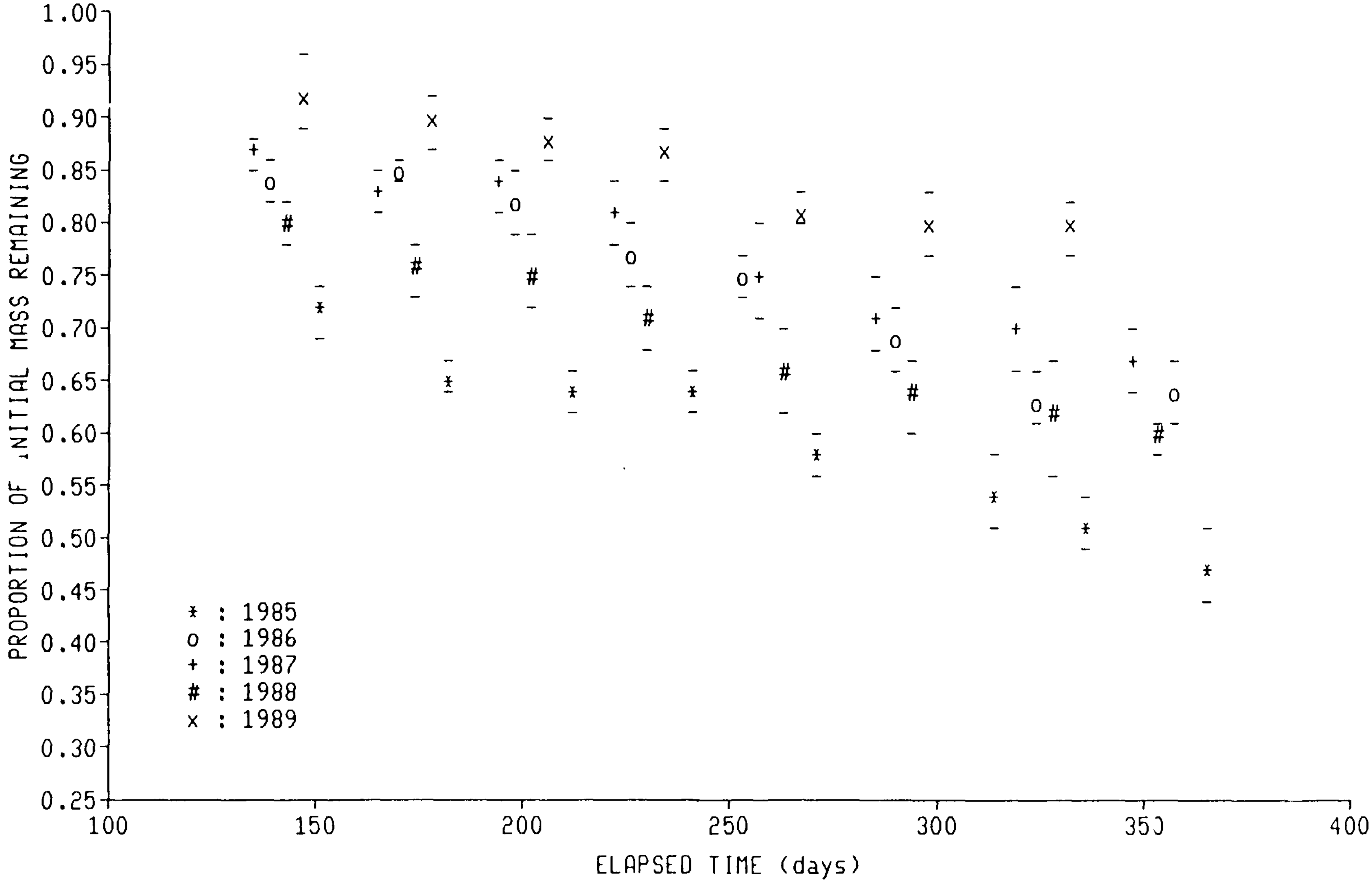


Figure 35. Proportion (X) of initial dry matter mass remaining for bulk maple leaf samples retrieved from the control unit hardwood stand during the five consecutive annual experiments completed to date.

ANOVA Results - Summary

The following outline summarizes the results of ANOVA on transformed dry matter mass loss data.

I. Subunits

A. Plantations
1. Pine
a. Individual fascicles decomposed faster in the ground and control plantations than in the antenna plantation.
b. Bulk samples decomposed faster in the ground and control plantations than in the antenna plantation.
2. Oak
a. Using individual leaves, no diffeences were were detected.
b. Bulk samples decomposed faster in the ground and antenna plantations than in the control plantation.
3. Maple
a. Bulk samples decomposed faster in the ground and antenna plantations than in the control plantation.

B. Hardwood Stands
1. Pine
a. Using individual fascicles, no difference was detected between hardwood stands.
b. Bulk samples decomposed faster in the antenna hardwood stand than in the control hardwood stand.
2. Oak
a. Individual leaves decomposed faster in the antenna hardwood stand than in the control stand.
b. With bulk samples, no differences were detected.
3. Maple
a. Bulk samples decomposed fastest in the antenna hardwood stand.

II. Years

A. Plantations
1. Pine
a. For individual fascicles, years rank (from fastest to slowest): 1988 ≤ 1987 < 1986 < 1989 < 1985.
b. For bulk needle samples, years rank (from fastest to slowest): 1985 < 1989 < 1986 < 1988 < 1987.
2. Oak
a. For individual leaves, years rank (from fastest to slowest): 1987 < 1988 < 1989 < 1985 < 1986.
b. For bulk leaf samples, years rank (from fastest to slowest): 1989 < 1985 ≤ 1988 < 1987 ≤ 1986.
3. Maple
a. For bulk leaf samples, years rank (from fastest to slowest): 1985 < 1988 < 1986 ≤ 1987 < 1989.

B. Hardwood Stands
   1. Pine
      a. For individual fascicles, years rank (from fastest to slowest): 1985 < 1987 < 1988 ≤ 1986 < 1989.
      b. For bulk fascicle samples, years rank (from fastest to slowest): 1985 < 1989 ≤ 1987 ≤ 1986 < 1988.
   2. Oak
      a. For individual leaves, years rank (from fastest to slowest): 1989 < 1985 ≤ 1987 ≤ 1988 < 1986.
      b. For bulk leaf samples, years rank (from fastest to slowest): 1989 < 1985 < 1987 ≤ 1988 < 1986.
   3. Maple
      a. For bulk leaf samples, years rank (from fastest to slowest): 1985 < 1988 < 1986 ≤ 1987 < 1989.

Among the three study plantations, pine decomposition appears to proceed fastest under conditions prevailing at the ground and control sites. Bulk oak and maple samples decomposed fastest in the ground and antenna plantations; no differences among plantations were detected using individual oak leaves.

Comparing the two hardwood stands, decomposition of bulk pine samples, individual oak leaves and bulk maple samples has been faster in the antenna hardwood stand. No differences were detected using individual pine fascicles or bulk samples of oak.

It seems likely that the 1984-85 study incurred the best weather conditions to date for decomposition of all three litter species. Nevertheless, modification of the sample unit design for individual oak leaves and pine fascicles between the 1985-86 and 1986-87 studies has resulted in faster decomposition of individual oak leaf samples in the plantations since the modification was effected.

Oak samples decomposed relatively slowly in 1986. Maple samples decomposed most slowly in 1989. Pine samples showed little consistency in behavior among years, except for the tendency to decompose fastest in 1985.

The differences between litter species described above suggest that different sets of covariates may be needed for each species (and, in some cases, for each sample type), in order to explain differences in decomposition rate among sites and years. The differences in rankings of the years for litter species suggest that covariates describing the initial condition of the annual litter supply for each species might be effective.

The uniformly significant year by site interactions are of special interest, because they might represent evidence of an ELF field effect. These interactions signify that the ranking of plantations and hardwood stands (according to proportion of initial dry matter mass remaining) has not remained constant for the five study years. Important questions here are: When and how often have site rankings shifted? Answering this question will be a high priority for the coming year, and will be addressed using ANOVA (and ANACOV) repeatedly within the multi-year data set, each with data from only one year. Analyses without the year by site interaction will not be presented in future reports.

Covariate Selection for Preliminary ANACOV

Prerequisites for including a variable in our covariate analyses are 1) significant correlation ($p \leq 0.05$) with transformed mass loss data, 2) a reasonable likelihood that the variable can eventually be shown to be independent of ELF field influence, and 3) a reasonable hypothetical relationship between mass loss and the potential covariate.

Potential covariates can be categorized as follows.

1) Covariates which characterize the annual parent litter collections, prior to disbursal, provide a single value which applies to all samples prepared from a parent collection.

2) Covariates which characterize, prior to disbursal, the individual leaf samples placed in the field, provide each sample with a unique value.

3) Covariates which characterize the litter samples retrieved from the field also provide each sample with a unique value.

4) Covariates which characterize temporally unchanging aspects of the study sites provide samples retrieved in different years with spatially dependent values.

5) Covariates which characterize dynamic aspects of the study sites and their weather provide individual samples with more or less unique values.

Because each year's parent litter collections are distributed to all sites, covariates in category 1 (e.g., initial content of N, P, K, Ca, Mg, and lignin) can be used to distinguish among years, but not among sites. Unfortunately, while Proc GLM permits ANACOV with these covariates, we have not yet found a way to evaluate multiple comparisons within these models. Therefore, unless these covariates explain all differences among years, we remain uncertain of how much they accomplish. This problem arises because there is only one estimate of parent litter nutrients for each year, and therefore perfect colinearity exists between these covariates and one of the degrees of freedom associated with years. This results in one fewer degrees of freedom associated with Type III sum of squares for Year, and 0 degrees of freedom associated with the covariate. When SAS detects this perfect colinearity, no estimates of adjusted means or standard errors are computed, and therefore no multiple comparisons are made.

At present, the only category 2 covariate is initial individual oak leaf density (g/cm^2). Because each leaf in the field has its own unique density value, this variable can help to explain differences among years as well as among sites. Although the annual parent collections representing each litter species

are made at the same location each year, both category 1 and category 2 covariates help to characterize the differences in substrate quality between the annual collections.

Category 3 covariates currently include the percent N, P, K, Ca, and Mg content of the retrieved bulk litter samples. Nutrient analysis has been scaled back, due to resource limitations, to analysis of samples retrieved during alternate months (May, July, September, and November samples). Samples retrieved during the remaining months (and the unutilized portions of analyzed samples) have been archived, anticipating that further analysis (possibly including lignin content) may eventually be warranted and possible. An alternative approach would be to estimate the nutrient contents for intervening sampling dates by interpolation, and to use the estimates along with the measurements in covariates for ANACOV.

Category 4 covariates include the 1987 values for numbers and basal areas per hectare of stumps or live stems by species. These covariates are expected to change little with time and, therefore, can not help to explain differences among years. Also because these variables change little with time, there is a greater possibility (than with temporally variable covariates) that they may eventually be shown to be correlated spatially with measures of ELF field exposure. On the other hand, because each of these covariates varies among the three contiguous plots comprising each individual plantation and hardwood stand subunit, as well as among the subunits themselves, there is reason to hope that they can be shown to be statistically independent of the ELF field exposures and/or intensities. Also, any variable with values which could not have changed since exposure to ELF fields began must be independent of ELF (i.e., could not possibly be affected by ELF fields). If, however, as we suspect, the numbers of certain spp. of stumps in the plantations should turn out to be surrogates for the shading (or other) effect of sprouts on decomposition, then these covariates might effectively mask an effect of ELF fields on sprouting capacity or rate of sprout growth. For this reason, data on the extent of sprouting is being gathered and automated for consideration as covariates. The mechanical severence of sprouts from all three plantations in 1986, and from the ground and antenna plantations in 1989, will make analysis and interpretation of this data very difficult. We have anticipated from the beginning of the research program, however, that it was going to be much more difficult to explain differences between years and sites in the plantations than in the hardwood stands. The temporally evolving values of a number of potentially important covariates are changing at different rates in the different plantations, with intermittent disturbances imposed in addition.

Category 5 covariates include measures of air and surface soil temperatures, precipitation event frequency, and total precipitation. Only cumulative variables have been used to date. These have also been the most useful covariates to date. Unfortunately, our success with these variables to date almost certainly underestimates their importance biologically, because

they are calculated independently of one another. For this reason, we are working on construction of a covariate similar to actual evapotranspiration (AET: e.g., Thornthwaite and Mather 1957, Meentemeyer and Berg 1986), which will integrate temperature, precipitation, water-holding capacity, and lattitude.

The following variables have been used in one or more ANACOV model presented in this report:

DENSITY - a measure of the densities (g/cm^2) of individual oak leaves

ATDDRT - the running total, on each plot and for each year, of air temperature degree days (30 cm above ground level; 4.4°C basis)

ST5DDRT - the running total, on each plot and for each year, of soil temperature degree days (5 cm below ground level; 4.4°C basis)

PR.01RT - the running total, on each site and for each year, of days with rainfall totalling at least 0.01 inch.

PR.1RT - the running total, on each site and for each year, of days with rainfall totalling at least 0.1 inch.

PRWRT - the running total, on each site and for each year, of precipitation

In response to one of our reviewers, we are providing the weather-related covariate data sets for 1985 through 1989, as Tables 48 - 57. Even and odd numbered tables present data representing temperature- and precipitation-related covariates, respectively, for successive years.

ANACOV Results - Individual Fascicle/Leaf Samples

The ANACOVs presented below were selected because they provide insight for explanation of significant differences detected by the 3-way ANOVAs discussed above. As mentioned above, in this year's report, litter decomposition ANACOV models for each litter sample type and species, on both the plantation and hardwood stand subunits, were evaluated both with and without year by site interactions. Both types of model are presented for comparison throughout the report. For each data subset, the ANACOV table always precedes the table of means and comparisons, and the model without the year by site interaction always precedes the model with the interaction specified.

Individual Pine Fascicles

Table 58 presents the ANACOV table for detection of significant differences in dry matter mass loss among years,

Table 48. Values of ATDDRT, the running total of air temperature degree days (4.4°C basis), and ST5DDRT, the running total of soil temperature degree days (5 cm depth, 4.4°C basis), achieved by each sampling date in 1985.

	30 Apr	2 Jun	2 Jul	31 Jul	27 Aug	12 Oct	2 Nov
ATDDRT							
111	89	318	591	950	1258	1560	1613
112	88	319	592	948	1257	1556	1607
113	88	318	591	946	1255	1556	1607
211	87	318	588	940	1251	1557	1615
212	87	318	597	961	1275	1579	1637
213	87	317	579	919	1227	1535	1594
311	113	368	657	1031	1344	1647	1707
312	114	380	673	1047	1363	1680	1744
313	115	373	664	1038	1352	1661	1720
221	88	320	593	951	1260	1562	1621
222	88	321	595	948	1255	1555	1610
223	88	315	582	930	1233	1527	1578
321	106	381	681	1067	1394	1717	1790
322	109	381	677	1061	1386	1707	1777
323	105	378	674	1058	1382	1703	1773
ST5DDRT							
111	59	336	675	1069	1394	1750	1797
112	63	351	704	1090	1412	1768	1827
113	60	335	678	1079	1411	1784	1843
211	63	355	710	1131	1482	1865	1919
212	59	339	677	1073	1412	1774	1827
213	72	390	753	1176	1531	1903	1957
311	49	322	642	1032	1364	1724	1764
312	49	321	664	1085	1437	1814	1858
313	50	321	648	1041	1379	1759	1817
221	28	197	399	683	909	1116	1142
222	31	231	472	802	1102	1437	1494
223	33	228	462	779	1067	1375	1424
321	17	209	444	770	1071	1423	1485
322	23	218	447	766	1058	1394	1455
323	16	207	449	778	1077	1418	1482

Table 49. Values of PRWRT, the running total of precipitation, PR.01RT, the running total of days with precipitation events totaling at least 0.01 inch, and PR.10RT, the running total of days with precipitation events totaling at least 0.10 inch, achieved by each sampling date in 1985.

	30 Apr	2 Jun	2 Jul	31 Jul	27 Aug	12 Oct	2 Nov
<u>PRWRT</u>							
11	3.3	8.3	10.0	12.6	17.6	26.2	27.8
21	3.3	8.3	10.1	12.9	17.9	26.7	28.2
31	1.7	5.9	8.0	8.9	11.6	21.1	22.8
22	3.3	8.3	10.1	12.9	17.9	26.7	28.2
32	1.7	5.9	8.0	8.9	11.6	21.1	22.8
<u>PR.01RT</u>							
11	14	29	39	46	57	83	91
21	14	27	37	46	57	83	92
31	10	27	41	48	62	85	90
22	14	27	37	46	57	83	92
32	10	27	41	48	62	85	90
<u>PR.1RT</u>							
11	9	14	19	25	35	49	52
21	9	15	21	25	35	50	52
31	6	15	22	25	31	44	47
22	9	15	21	25	35	50	52
32	6	15	22	25	31	44	47

Table 50. Values of ATDDRT, the running total of air temperature degree days (4.4°C basis), and ST5DDRT, the running total of soil temperature degree days (5 cm depth, 4.4°C basis), achieved by each sampling date in 1986.

	7 May	3 Jun	1 Jul	30 Jul	4 Sep	1 Oct	6 Nov
<u>ATDDRT</u>							
111	132	368	650	1069	1456	1628	1694
112	132	369	653	1081	1506	1674	1739
113	137	364	634	1043	1442	1599	1661
211	120	363	654	1078	1482	1648	1715
212	120	367	662	1088	1492	1658	1727
213	122	374	673	1105	1509	1675	1745
311	149	394	697	1131	1539	1748	1846
312	154	401	712	1154	1559	1772	1874
313	151	394	695	1126	1529	1739	1835
221	123	369	657	1075	1479	1640	1710
222	122	366	654	1072	1476	1637	1704
223	116	350	628	1038	1442	1602	1665
321	163	421	728	1161	1577	1790	1892
322	162	417	722	1154	1570	1783	1880
323	160	417	722	1153	1569	1783	1884
<u>ST5DDRT</u>							
111	104	389	738	1186	1620	1839	1933
112	103	377	703	1138	1573	1792	1895
113	101	376	711	1148	1584	1808	1915
211	105	393	737	1192	1638	1862	1952
212	89	354	668	1100	1517	1725	1814
213	134	463	809	1282	1755	2001	2109
311	100	373	704	1156	1622	1845	1929
312	104	389	735	1194	1668	1893	2002
313	87	332	643	1075	1523	1745	1841
221	65	228	437	755	1083	1264	1378
222	71	279	523	887	1256	1459	1588
223	73	283	527	896	1251	1423	1493
321	75	294	551	923	1311	1512	1628
322	73	281	525	887	1263	1463	1574
323	73	278	530	902	1283	1484	1605

Table 51. Values of PRWRT, the running total of precipitation, PR.01RT, the running total of days with precipitation events totaling at least 0.01 inch, and PR.10RT, the running total of days with precipitation events totaling at least 0.10 inch, achieved by each sampling date in 1986.

	7 May	3 Jun	1 Jul	30 Jul	4 Sep	1 Oct	6 Nov
PRWRT							
11	1.2	1.2	2.3	4.1	7.6	9.9	13.4
21	0.5	0.5	1.5	3.3	6.8	9.2	12.7
31	0.6	0.9	2.8	5.1	7.7	10.4	13.5
22	0.5	0.5	1.5	3.3	6.8	9.2	12.7
32	0.6	0.9	2.8	5.1	7.7	10.4	13.5
PR.01RT							
11	6	6	15	24	43	54	68
21	5	6	15	24	43	54	68
31	4	7	18	25	42	52	64
22	5	6	15	24	43	54	68
32	4	7	18	25	42	52	64
PR.1RT							
11	2	2	5	11	21	27	34
21	1	1	4	10	20	26	33
31	2	3	10	16	24	33	39
22	1	1	4	10	20	26	33
32	2	3	10	16	24	33	39

Table 52. Values of ATDDRT, the running total of air temperature degree days (4.4°C basis), and ST5DDRT, the running total of soil temperature degree days (5 cm depth, 4.4°C basis), achieved by each sampling date in 1987.

	29 Apr	27 May	25 Jun	23 Jul	27 Aug	24 Sep	28 Oct
ATDDRT							
111	115	264	673	1049	1516	1757	1833
112	115	266	680	1058	1527	1769	1846
113	115	265	676	1053	1521	1763	1839
211	119	274	688	1064	1536	1783	1861
212	121	279	696	1075	1554	1812	1893
213	123	287	709	1091	1573	1828	1910
311	146	340	771	1160	1646	1899	1989
312	150	351	806	1223	1746	2035	2142
313	142	330	755	1138	1616	1871	1960
221	126	289	698	1067	1536	1787	1871
222	121	282	688	1054	1520	1769	1852
223	115	268	669	1031	1489	1729	1804
321	159	360	789	1167	1651	1911	2009
322	158	358	785	1174	1665	1930	2030
323	157	357	781	1160	1647	1910	2010
ST5DDRT							
111	88	294	684	1056	1542	1819	1945
112	79	272	666	1037	1514	1781	1891
113	97	316	736	1129	1629	1909	2020
211	87	278	666	1047	1537	1811	1924
212	84	264	660	1046	1549	1830	1950
213	112	342	764	1163	1685	1984	2110
311	82	275	678	1076	1601	1898	2024
312	68	245	620	996	1506	1797	1931
313	96	306	713	1114	1636	1927	2040
221	50	167	460	776	1201	1445	1566
222	59	191	498	824	1264	1522	1641
223	61	199	540	878	1321	1559	1637
321	60	200	543	887	1358	1624	1741
322	45	166	467	786	1228	1481	1588
323	76	231	574	930	1408	1679	1810

Table 53. Values of PRWRT, the running total of precipitation, PR.01RT, the running total of days with precipitation events totaling at least 0.01 inch, and PR.10RT, the running total of days with precipitation events totaling at least 0.10 inch, achieved by each sampling date in 1987.

	29 Apr	27 May	25 Jun	23 Jul	27 Aug	24 Sep	28 Oct
PRWRT							
11	1.0	3.1	6.3	12.6	15.3	17.4	19.7
21	1.1	3.3	6.4	12.7	15.7	18.2	20.6
31	0.9	2.3	5.3	10.1	15.0	17.2	19.6
22	1.1	3.3	6.4	12.7	15.7	18.2	20.6
32	0.9	2.3	5.3	10.1	15.0	17.2	19.6
PR.01RT							
11	10	17	32	48	59	69	85
21	11	18	33	49	64	75	89
31	13	21	35	48	64	75	91
22	11	18	33	49	64	75	89
32	13	21	35	48	64	75	91
PR.1RT							
11	3	8	15	25	29	34	42
21	3	8	15	25	29	35	42
31	4	8	14	25	34	40	48
22	3	8	15	25	29	35	42
32	4	8	14	25	34	40	48

Table 54. Values of ATDDRT, the running total of air temperature degree days (4.4°C basis), and ST5DDRT, the running total of soil temperature degree days (5 cm depth, 4.4°C basis), achieved by each sampling date in 1988.

	4 May	1 Jun	29 Jun	28 Jul	31 Aug	28 Sep	2 Nov
<u>ATDDRT</u>							
111	55	290	669	1089	1531	1749	1804
112	57	295	675	1094	1579	1818	1883
113	56	292	660	1059	1522	1751	1811
211	63	311	704	1152	1647	1883	1946
212	67	317	712	1158	1653	1889	1953
213	70	329	726	1170	1665	1901	1965
311	88	364	770	1216	1722	1966	2033
312	95	384	813	1295	1859	2168	2267
313	86	359	766	1214	1718	1973	2048
221	102	359	722	1146	1627	1859	1924
222	100	350	709	1101	1579	1808	1869
223	95	336	687	1098	1573	1794	1852
321	108	394	796	1234	1725	1972	2042
322	107	389	788	1215	1701	1943	2010
323	104	385	784	1219	1718	1971	2043
<u>ST5DDRT</u>							
111	25	222	570	997	1502	1771	1867
112	38	284	660	1084	1582	1847	1941
113	43	297	683	1120	1631	1904	2004
211	34	253	609	1034	1532	1792	1880
212	52	324	731	1201	1732	2001	2084
213	46	302	689	1136	1656	1931	2025
311	34	295	703	1149	1663	1935	2026
312	30	283	684	1126	1655	1937	2042
313	43	312	724	1173	1702	1994	2109
221	16	162	436	770	1177	1403	1495
222	22	202	504	850	1250	1436	1473
223	22	215	542	926	1375	1596	1653
321	31	218	523	885	1348	1604	1701
322	26	194	484	838	1283	1531	1620
323	22	183	479	839	1303	1548	1636

Table 55. Values of PRWRT, the running total of precipitation, PR.01RT, the running total of days with precipitation events totaling at least 0.01 inch, and PR.10RT, the running total of days with precipitation events totaling at least 0.10 inch, achieved by each sampling date in 1988.

	4 May	1 Jun	29 Jun	28 Jul	31 Aug	28 Sep	2 Nov
<u>PRWRT</u>							
11	0.3	1.4	2.3	5.3	12.2	16.3	19.9
21	0.3	1.5	2.3	5.1	11.9	15.9	19.5
31	0.9	1.6	3.9	5.7	10.8	13.8	16.5
22	0.3	1.5	2.3	5.1	11.9	15.9	19.5
32	0.9	1.6	3.9	5.7	10.8	13.8	16.5
<u>PR.01RT</u>							
11	3	12	22	29	44	57	78
21	3	11	19	24	39	51	71
31	4	13	18	29	46	56	76
22	3	11	19	24	39	51	71
32	4	13	18	29	46	56	76
<u>PR.1RT</u>							
11	1	5	8	11	22	30	39
21	1	5	8	11	24	32	41
31	3	5	9	11	21	29	36
22	1	5	8	11	24	32	41
32	3	5	9	11	21	29	36

Table 56. Values of ATDDRT, the running total of air temperature degree days (4.4°C basis), and ST5DDRT, the running total of soil temperature degree days (5 cm depth, 4.4°C basis), achieved by each sampling date in 1989.

	12 May	10 Jun	8 Jul	5 Aug	9 Sep	9 Oct	13 Nov
<u>ATDDRT</u>							
111	41	299	643	1058	1462	1628	1724
112	43	305	651	1070	1479	1644	1742
113	42	299	637	1048	1449	1612	1708
211	45	314	673	1107	1520	1696	1798
212	44	312	666	1093	1503	1674	1773
213	46	317	670	1099	1512	1684	1783
311	64	378	774	1231	1692	1890	2008
312	67	409	832	1309	1800	2014	2140
313	60	345	714	1152	1584	1767	1877
221	49	330	679	1098	1503	1680	1784
222	46	314	655	1063	1460	1629	1724
223	43	307	638	1046	1441	1608	1700
321	67	356	718	1144	1569	1759	1878
322	64	343	691	1105	1514	1 96	1811
323	69	363	728	1158	1587	1780	1901
<u>ST5DDRT</u>							
111	39	283	610	1024	1451	1653	1722
112	53	315	644	1041	1455	1654	1728
113	50	303	653	1084	1540	1767	1849
211	50	307	631	1038	1471	1681	1750
212	50	319	674	1102	1539	1743	1809
213	69	371	764	1232	1707	1906	1978
311	40	322	685	1140	1618	1836	1906
312	39	327	684	1125	1608	1836	1922
313	75	396	777	1237	1738	1976	2064
221	20	217	476	813	1177	1349	1413
222	22	231	501	846	1225	1414	1478
223	16	215	482	825	1195	1372	1431
321	16	234	525	895	1295	1495	1574
322	16	229	491	857	1253	1453	1531
323	8	213	500	871	1272	1472	1554

Table 57. Values of PRWRT, the running total of precipitation, PR.01RT, the running total of days with precipitation events totaling at least 0.01 inch, and PR.10RT, the running total of days with precipitation events totaling at least 0.10 inch, achieved by each sampling date in 1989.

	12 May	10 Jun	8 Jul	5 Aug	9 Sep	9 Oct	13 Nov
PRWRT							
11	0.8	4.6	6.4	7.9	12.1	13.4	16.7
21	0.8	4.9	6.6	8.0	11.8	12.9	16.0
31	0.7	4.4	5.6	6.3	8.1	8.6	11.8
22	0.8	4.9	6.6	8.0	11.8	12.9	16.0
32	0.7	4.4	5.6	6.3	8.1	8.6	11.8
PR.01RT							
11	8	23	31	38	49	59	79
21	8	23	31	38	49	60	82
31	12	26	33	41	49	58	75
22	8	23	31	38	49	60	82
32	12	26	33	41	49	58	75
PR.1RT							
11	3	11	16	20	27	29	37
21	3	11	16	20	28	30	38
31	2	11	15	18	24	26	33
22	3	11	16	20	28	30	38
32	2	11	15	18	24	26	33

monthly sampling dates, and plantations, using ATDDRT as the sole covariate. Table 59 presents 1) means and standard errors for the treatments (years, months, plantations), 2) detectable differences for each treatment based on 95 percent confidence intervals, and 3) significant differences detected by ANACOV and identified by SAS Proc GLM's Least Square Means procedure (SAS Institute Inc. 1985). As in previous years' reports, the analysis summarized in Tables 58 and 59 did not evaluate year by site interactions. Tables 60 and 61 represent an additional ANACOV performed on the same data, but including the year by site interaction. Thus, Tables 58 through 61 present results of the plantation ANACOVs (using ATDDRT as the sole covariate).

Individual pine fascicles placed in the ground plantation decomposed faster than those placed in the antenna or control plantations, when ATDDRT patterns at the three plantations are accounted for, and when the year by site interaction is included. Without the interaction, decomposition at the antenna plantation appeared to proceed significantly slower than at the control plantation as well. Comparing years in the plantations, 1987 and 1988 samples decomposed fastest (n.s.d., $\alpha = 0.05$) and 1985 and 1989 samples slowest (n.s.d.). Significant monthly progress occurred. Detectable differences were extremely low for years and sites (well below 1 percent of the mean values), and satisfactory for months (below 2.5 percent). Low detectable differences account for the significance of some of the differences between very close mean values. The year by site interaction was highly significant, did not affect detectable differences, but did result in explanation of the difference detected by ANOVA between the antenna and control plantations.

Tables 62 - 65 present the results of ANACOV for the plantations, with both ATDDRT and PR.01RT as covariates. Again, individual pine fascicles placed in the ground plantation decomposed faster than those in either the antenna or ground plantations. Comparing years, decomposition proceeded fastest in 1986 and 1988 (n.s.d.), slowest in 1985, and at an intermediate rate during 1987 and 1989 (n.s.d.). This combination of covariates explained nearly all differences between months. Detectable differences remain well below 1 percent for years and plantations, and below 3 percent for months. Again, the year by site interaction was highly significant and had little effect on detectable differences, but, in this case, the interaction did not explain any additional differences. Figure 36 presents graphically the results of 3-way ANOVA and the two ANACOV models of individual pine fascicle decomposition in the three plantations.

For the hardwood stands, Tables 66 - 69 present the results of ANACOV models using PR.1RT as the sole covariate. Decomposition has proceeded at comparable rates in the two hardwood stands. Comparing years, without the year by stand interaction, decomposition was fastest in 1985 and 1986 (n.s.d.), slowest in 1989, and occurred at an intermediate rate during 1987 and 1988 (n.s.d.). Detectable differences were well below 1

Table 58. Covariance analysis table for detection of differences in dry matter mass loss (arcsin square root of the proportion of initial mass remaining) from **Individual Pine** needles in the three **Plantation** subunits, using one covariate: **ATDDRT**, running total of air temperature degree days (4.4°C basis).

Source of Variation	df	SS	Type III SS	F	Signif. of F	r^2
Model	13	23.62		747.27	0.0000	0.81
Year	4		0.14	14.25	0.0001	
Month	6		0.34	23.21	0.0001	
Plantation	2		0.07	14.48	0.0001	
ATDDRT	1		0.02	8.84	0.0030	
Error	2339	5.68				
Corrected Total	2352	29.30				

Table 59. Adjusted means, standard errors, detectable differences, and significantly different pairs of means, based on the model analyzed in Table 60.

Source of Variation	Adjusted Mean[a]	Standard Error	Detectable Difference[b]	Significant Differences[c]						
Year					5	6	7	8		
1985	1.166	0.002	0.34	1985						
1986	1.156	0.002	0.34	1986	*					
1987	1.144	0.003	0.51	1987	*	*				
1988	1.144	0.003	0.51	1988	*	*				
1989	1.163	0.002	0.34	1989		*	*	*		
Month					1	2	3	4	5	6
May	1.254	0.013	2.03	May						
June	1.232	0.010	1.59	June	*					
July	1.192	0.005	0.82	July	*	*				
August	1.164	0.003	0.51	Aug	*	*	*			
September	1.112	0.008	1.41	Sept	*	*	*	*		
October	1.076	0.011	2.00	Oct	*	*	*	*	*	
November	1.052	0.012	2.42	Nov	*	*	*	*	*	*
Plantation					G	A	C			
Ground	1.148	0.002	0.34	Ground						
Antenna	1.161	0.002	0.34	Antenna	*					
Control	1.155	0.002	0.34	Control	*	*				

a/ mean of transformed data

b/ estimated shift in the sample mean which would be detected 95 percent of the time (α = .05), calculated as $t_{.05,n}$*S.E./Mean, and expressed as a percentage of the sample mean

c/ α = .05, least squares means pairwise comparisons

Table 60. Covariance analysis table (including year * plantation interaction) for detection of differences in dry matter mass loss (arcsin square root of the proportion of initial mass remaining) from **Individual Pine** needles in the three **Plantation** subunits, using one covariate: **ATDDRT**, running total of air temperature degree days (4.4°C basis).

Source of Variation	df	SS	Type III SS	F	Signif. of F	r^2
Model	21	23.72		471.67	0.0000	0.81
Year	4		0.13	14.02	0.0001	
Month	6		0.33	22.67	0.0001	
Plantation	2		0.06	11.87	0.0001	
Year*Plantation	8		0.10	5.28	0.0001	
ATDDRT	1		0.02	8.29	0.0040	
Error	2331	5.58				
Corrected Total	2352	29.30				

Table 61. Adjusted means, standard errors, detectable differences, and significantly different pairs of means, based on the model analyzed in Table 62.

Source of Variation	Adjusted Mean[a]	Standard Error	Detectable Difference[b]	Significant Differences[c]						
Year					5	6	7	8		
1985	1.166	0.002	0.34	1985						
1986	1.156	0.002	0.34	1986	*					
1987	1.144	0.003	0.51	1987	*	*				
1988	1.144	0.003	0.51	1988	*	*				
1989	1.163	0.002	0.34	1989		*	*	*		
Month					1	2	3	4	5	6
May	1.255	0.013	2.03	May						
June	1.233	0.010	1.59	June	*					
July	1.192	0.005	0.82	July	*	*				
August	1.164	0.003	0.51	Aug	*	*	*			
September	1.111	0.008	1.41	Sept	*	*	*	*		
October	1.076	0.011	2.00	Oct	*	*	*	*	*	
November	1.051	0.013	2.42	Nov	*	*	*	*	*	*
Plantation					G	A	C			
Ground	1.148	0.002	0.34	Ground						
Antenna	1.161	0.002	0.34	Antenna	*					
Control	1.155	0.002	0.34	Control	*					

a/ mean of transformed data
b/ estimated shift in the sample mean which would be detected 95 percent of the time (α = .05), calculated as $t_{.05,n}$*S.E./Mean, and expressed as a percentage of the sample mean
c/ α = .05, least squares means pairwise comparisons

Table 62. Covariance analysis table for detection of differences in dry matter mass loss (arcsin square root of the proportion of initial mass remaining) from **Individual Pine** needles in the three **Plantation** subunits, using two covariates: 1) **ATDDRT**, running total of air temperature degree days (4.4°C basis), and 2) **PR.01RT**, running total of days with precipitation events totalling at least 0.01 inch.

Source of Variation	df	SS	Type III SS	F	Signif. of F	r^2
Model	14	23.91		740.85	0.0000	0.82
Year	4		0.40	42.85	0.0001	
Month	6		0.07	14.54	0.0001	
Plantation	2		0.07	5.17	0.0001	
ATDDRT	1		0.03	12.63	0.0004	
PR.01RT	1		0.29	127.12	0.0001	
Error	2338	5.39				
Corrected Total	2352	29.30				

Table 63. Adjusted means, standard errors, detectable differences, and significantly different pairs of means, based on the model analyzed in Table 64.

Source of Variation	Adjusted Mean[a]	Standard Error	Detectable Difference[b]	Significant Differences[c]						
Year					5	6	7	8		
1985	1.199	0.004	0.65	1985						
1986	1.131	0.003	0.52	1986	*					
1987	1.169	0.003	0.50	1987	*	*				
1988	1.127	0.003	0.52	1988	*		*			
1989	1.170	0.002	0.34	1989	*	*		*		
Month					1	2	3	4	5	6
May	1.156	0.016	2.71	May						
June	1.164	0.011	1.85	June						
July	1.155	0.006	1.02	July						
August	1.158	0.003	0.51	Aug						
September	1.150	0.008	1.36	Sept						
October	1.157	0.013	2.20	Oct						
November	1.176	0.016	2.67	Nov					*	*
Plantation					G	A	C			
Ground	1.151	0.002	0.34	Ground						
Antenna	1.164	0.002	0.34	Antenna	*					
Control	1.162	0.002	0.34	Control	*					

a/ mean of transformed data

b/ estimated shift in the sample mean which would be detected 95 percent of the time (α = .05), calculated as $t_{.05,n}$*S.E./Mean, and expressed as a percentage of the sample mean

c/ α = .05, least squares means pairwise comparisons

Table 64. Covariance analysis table (including year * plantation interaction) for detection of differences in dry matter mass loss (arcsin square root of the proportion of initial mass remaining) from **Individual Pine** needles in the three **Plantation** subunits, using two covariates: 1) **ATDDRT**, running total of air temperature degree days (4.4°C basis), and 2) **PR.01RT**, running total of days with precipitation events totalling at least 0.01 inch.

Source of Variation	df	SS	Type III SS	F	Signif. of F	r^2
Model	22	24.00		479.81	0.0000	0.82
Year	4		0.38	42.34	0.0001	
Month	6		23.11	5.31	0.0001	
Plantation	2		0.11	12.09	0.0001	
Year*Plantation	8		0.10	5.05	0.0001	
ATDDRT	1		0.02	11.68	0.0006	
PR.01RT	1		0 28	124.80	0.0001	
Error	2330	5.30				
Corrected Total	2352	29.30				

Table 65. Adjusted means, standard errors, detectable differences, and significantly different pairs of means, based on the model analyzed in Table 66.

Source of Variation	Adjusted Mean[a]	Standard Error	Detectable Difference[b]	Significant Differences[c]						
Year					5	6	7	8		
1985	1.200	0.004	0.70	1985						
1986	1.131	0.003	0.52	1986	*					
1987	1.170	0.003	0.50	1987	*	*				
1988	1.127	0.003	0.52	1988	*		*			
1989	1.170	0.002	0.34	1989	*	*		*		
Month					1	2	3	4	5	6
May	1.156	0.016	2.71	May						
June	1.164	0.012	2.02	June						
July	1.155	0.006	1.02	July						
August	1.157	0.003	0.51	Aug						
September	1.149	0.009	1.54	Sept						
October	1.157	0.013	2.20	Oct						
November	1.177	0.017	2.83	Nov					*	*
Plantation					G	A	C			
Ground	1.152	0.002	0.34	Ground						
Antenna	1.164	0.002	0.34	Antenna	*					
Control	1.162	0.002	0.34	Control	*					

a/ mean of transformed data
b/ estimated shift in the sample mean which would be detected 95 percent of the time (α = .05), calculated as $t_{.05,n}$*S.E./Mean, and expressed as a percentage of the sample mean
c/ α = .05, least squares means pairwise comparisons

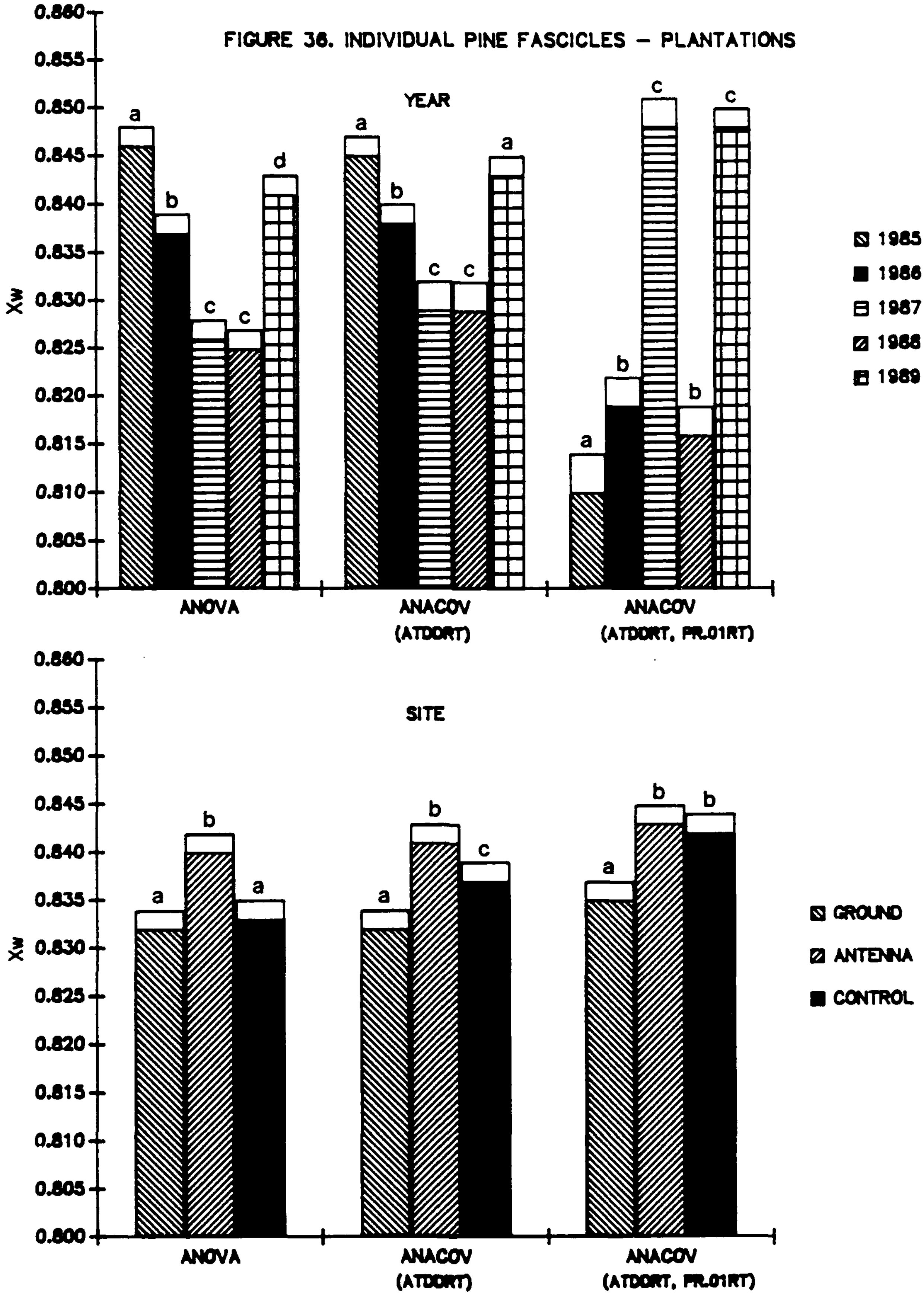


FIGURE 36. INDIVIDUAL PINE FASCICLES - PLANTATIONS
YEAR
Xw
0.860
0.855
0.850
0.845
0.840
0.835
0.830
0.825
0.820
0.815
0.810
0.805
0.800
a
b
c
c
d
a
b
c
c
a
a
b
c
b
c
ANOVA
ANACOV (ATDDRT)
ANACOV (ATDDRT, PR.01RT)
1985
1986
1987
1988
1989
SITE
a
b
a
a
b
c
a
b
b
GROUND
ANTENNA
CONTROL

Table 66. Covariance analysis table for detection of differences in dry matter mass loss (arcsin square root of the proportion of initial mass remaining) from **Individual Pine** needles in the two **Hardwood Stand** subunits, using one covariate: **PR.1RT**, running total of days with precipitation events totalling at least 0.10 inch.

Source of Variation	df	SS	Type III SS	F	Signif. of F	r^2
Model	13	19.10		655.80	0.0000	0.82
Year	4		0.19	21.05	0.0001	
Month	7		0.60	38.45	0.0001	
Hardwood Stand	2		0.00	0.47	0.4942	
PR.1RT	1		0.21	92.94	0.0001	
Error	1833	4.11				
Corrected Total	1846	23.21				

Table 67. Adjusted means, standard errors, detectable differences, and significantly different pairs of means, based on the model analyzed in Table 68.

Source of Variation	Adjusted Mean[a]	Standard Error	Detectable Difference[b]	Significant Differences[c]							
Year					5	6	7	8			
1985	1.151	0.004	0.68	1985							
1986	1.156	0.003	0.51	1986							
1987	1.162	0.003	0.51	1987	*						
1988	1.164	0.003	0.51	1988	*	*					
1989	1.183	0.003	0.50	1989	*	*	*	*			
Month					1	2	3	4	5	6	7
May	1.226	0.008	1.28	May							
June	1.221	0.006	0.96	June							
July	1.204	0.004	0.65	July	*	*					
August	1.181	0.003	0.50	Aug	*	*	*				
September	1.127	0.003	0.52	Sept	*	*	*	*			
October	1.109	0.006	1.06	Oct	*	*	*	*	*		
November	1.105	0.008	1.42	Nov	*	*	*	*	*		
December	1.132	0.010	1.73	Dec	*	*	*	*		*	*
Hardwood Stand					A	C					
Antenna	1.164	0.002	0.34	Antenna							
Control	1.162	0.002	0.34	Control							

a/ mean of transformed data
b/ estimated shift in the sample mean which would be detected 95 percent of the time (α = .05), calculated as $t_{.05,n}$*S.E./Mean, and expressed as a percentage of the sample mean
c/ α = .05, least squares means pairwise comparisons

Table 68. Covariance analysis table (including year * stand interaction) for detection of differences in dry matter mass loss (arcsin square root of the proportion of initial mass remaining) from **Individual Pine** needles in the two **Hardwood Stand** subunits, using one covariate: **PR.1RT**, running total of days with precipitation events totalling at least 0.10 inch.

Source of Variation	df	SS	Type III SS	F	Signif. of F	r^2
Model	17	19.62		588.09	0.0000	0.85
Year	4		0.20	24.96	0.0001	
Month	7		0.48	34.63	0.0001	
Hardwood Stand	1		0.00	2.37	0.1241	
Year * Stand	4		0.52	65.95	0.0001	
PR.1RT	1		0.31	157.92	0.0001	
Error	1829	3.59				
Corrected Total	1846	23.21				

Table 69. Adjusted means, standard errors, detectable differences, and significantly different pairs of means, based on the model analyzed in Table 70.

Source of Variation	Adjusted Mean[a]	Standard Error	Detectable Difference[b]	Significant Differences[c]							
Year					5	6	7	8			
1985	1.165	0.004	0.67	1985							
1986	1.150	0.003	0.51	1986	*						
1987	1.169	0.003	0.50	1987		*					
1988	1.160	0.003	0.51	1988		*	*				
1989	1.184	0.003	0.50	1989	*	*	*	*			
Month					1	2	3	4	5	6	7
May	1.198	0.008	1.31	May							
June	1.200	0.006	0.98	June		*					
July	1.191	0.005	0.82	July		*	*				
August	1.176	0.003	0.50	Aug	*	*	*	*			
September	1.134	0.003	0.52	Sept	*	*	*	*			
October	1.128	0.006	1.04	Oct	*	*	*	*			
November	1.133	0.008	1.38	Nov	*	*	*	*			
December	1.167	0.010	1.68	Dec		*			*	*	*
Hardwood Stand							A		C		
Antenna	1.164	0.002	0.34	Antenna							
Control	1.167	0.002	0.34	Control							

a/ mean of transformed data
b/ estimated shift in the sample mean which would be detected 95 percent of the time (α = .05), calculated as $t_{.05,n}$*S.E./Mean, and expressed as a percentage of the sample mean
c/ α = .05, least squares means pairwise comparisons

percent for years and stands, and below 2 percent for months. Though the year by site interaction was highly significant, it had little effect on detectable differences, but significantly altered the means for some years, months, and stands. With the interaction included, decomposition proceeded fastest in 1986 (instead of in 1985), and slowest in 1989.

Tables 70 - 73 present results of ANACOV using both ST5DDRT and PRWRT as covariates. Again, no significant difference was detected between stands. Comparing years, without the year by stand interaction, decomposition was fastest in 1985, and slowest in 1988 and 1989 (n.s.d.). Detectable differences were well below 1 percent for year and stand, and below 2.5 percent for month. When the interaction term was included, it was highly significant, and, though detectable differences remained low, treatment level means changed enough to explain the difference in decomposition rate between 1986 and 1987. Otherwise, the ranking of years was unaffected, relative to ANACOV with PRWRT alone. Figure 37 depicts the results of ANOVA and ANACOV for individual pine fascicles in the hardwood stands.

Individual Oak Leaves

For the plantations, Tables 74 - 77 present the results of ANACOV models using PRWRT as the sole covariate. No significant differences were detected among the plantations. Comparing years, decomposition proceeded fastest in 1987, 1988, and 1989 (n.s.d.), and slowest in 1985 and 1986 (n.s.d.). Monthly progress in decomposition was significant. Detectable differences were approximately 1 percent for years, well below 1 percent for plantations, and well below 2.5 percent for months. Though the year by site interaction term was highly significant, detectable differences rose slightly when it was included, and means shifted slightly, but not enough to affect patterns of significance.

Tables 78 - 81 present the results of ANACOV for the plantations, using both ST5DDRT and PRWRT as covariates. No significant differences were detected among the plantations. Comparing years, the same pattern was apparent as for ANACOV with PRWRT alone. Also, most monthly differences were explained. Detectable differences were low for year and site again, but somewhat higher (nearly all below 5.5 percent) for months. Though the year by site interaction was highly significant, detectable differences rose only very slightly when it was included, and treatment level means changed slightly, but the patterns of significance for years and plantations remained the same. Figure 38 depicts the results of ANOVA and ANACOV for individual oak leaf decomposition in the plantations.

For the hardwood stands, Tables 82 - 85 present the results of ANACOV models using DENSITY and PRWRT as covariates. No significant difference was detected between the two hardwood stands. Comparing years, decomposition proceeded fastest in 1989 and slowest in 1986. Decomposition proceeded faster in 1988 than in 1985 or 1987 (n.s.d.). Monthly progress in decomposition was

Table 70. Covariance analysis table for detection of differences in dry matter mass loss (arcsin square root of the proportion of initial mass remaining) from **Individual Pine** needles in the two **Hardwood Stand** subunits, using two covariates: 1) **ST5DDRT**, running total of soil temperature degree days (5 cm below ground level; 4.4°C basis), and 2) **PRWRT**, running total of precipitation.

Source of Variation	df	SS	Type III SS	F	Signif. of F	r^2
Model	13	18.96		583.85	0.0000	0.82
Year	4		0.41	43.94	0.0001	
Month	7		0.00	13.94	0.0001	
Hardwood Stand	2		0.23	0.09	0.7662	
ST5DDRT	1		0.05	21.66	0.0001	
PRWRT	1		0.02	7.89	0.0050	
Error	1832	4.25				
Corrected Total	1846	23.21				

Table 71. Adjusted means, standard errors, detectable differences, and significantly different pairs of means, based on the model analyzed in Table 72.

Source of Variation	Adjusted Mean[a]	Standard Error	Detectable Difference[b]	Significant Differences[c]							
Year					5	6	7	8			
1985	1.125	0.004	0.70	1985							
1986	1.171	0.003	0.50	1986	*						
1987	1.159	0.004	0.68	1987	*	*					
1988	1.178	0.003	0.50	1988	*	*	*				
1989	1.185	0.003	0.50	1989	*	*	*				
Month					1	2	3	4	5	6	7
May	1.220	0.014	2.25	May							
June	1.216	0.011	1.77	June							
July	1.202	0.007	1.14	July	*	*					
August	1.191	0.003	0.49	Aug	*	*					
September	1.141	0.007	1.20	Sept	*	*	*	*			
October	1.118	0.011	1.93	Oct	*	*	*	*	*		
November	1.102	0.013	2.31	Nov	*	*	*	*	*	*	
December	1.119	0.014	2.45	Dec	*	*	*	*	*		*
Hardwood Stand					A	C					
Antenna	1.164	0.002	0.34	Antenna							
Control	1.163	0.002	0.34	Control							

a/ mean of transformed data
b/ estimated shift in the sample mean which would be detected 95 percent of the time (α = .05), calculated as $t_{.05,n}$*S.E./Mean, and expressed as a percentage of the sample mean
c/ α = .05, least squares means pairwise comparisons

Table 72. Covariance analysis table (including year * stand interaction) for detection of differences in dry matter mass loss (arcsin square root of the proportion of initial mass remaining) from **Individual Pine** needles in the two **Hardwood Stand** subunits, using two covariates: 1) **ST5DDRT**, running total of soil temperature degree days (5 cm below ground level; 4.4°C basis), and 2) **PRWRT**, running total of precipitation.

Source of Variation	df	SS	Type III SS	F	Signif. of F	r^2
Model	18	19.44		524.10	0.0000	0.84
Year	4		0.30	35.92	0.0001	
Month	7		0.19	13.42	0.0001	
Hardwood Stand	1		0.00	0.27	0.6056	
Year * Stand	4		0.48	58.39	0.0001	
ST5DDRT	1		0.05	24.99	0.0001	
PRWRT	1		0.09	41.89	0.0001	
Error	1828	3.77				
Corrected Total	1846	23.21				

Table 73. Adjusted means, standard errors, detectable differences, and significantly different pairs of means, based on the model analyzed in Table 74.

Source of Variation	Adjusted Mean[a]	Standard Error	Detectable Difference[b]	Significant Differences[c]							
Year					5	6	7	8			
1985	1.136	0.004	0.69	1985							
1986	1.165	0.003	0.50	1986	*						
1987	1.164	0.003	0.51	1987	*						
1988	1.178	0.003	0.50	1988	*	*	*				
1989	1.184	0.003	0.50	1989	*	*	*				
Month					1	2	3	4	5	6	7
May	1.202	0.014	2.28	May							
June	1.202	0.011	1.79	June							
July	1.193	0.007	1.15	July							
August	1.187	0.003	0.50	Aug							
September	1.145	0.006	1.03	Sept	*	*	*	*			
October	1.131	0.010	1.73	Oct	*	*	*	*	*		
November	1.120	0.012	2.10	Nov	*	*	*	*	*	*	
December	1.144	0.013	2.23	Dec	*	*	*	*		*	*
Hardwood Stand					A	C					
Antenna	1.165	0.002	0.34	Antenna							
Control	1.166	0.002	0.34	Control							

a/ mean of transformed data
b/ estimated shift in the sample mean which would be detected 95 percent of the time ($\alpha = .05$), calculated as $t_{.05,n}$*S.E./Mean, and expressed as a percentage of the sample mean
c/ $\alpha = .05$, least squares means pairwise comparisons

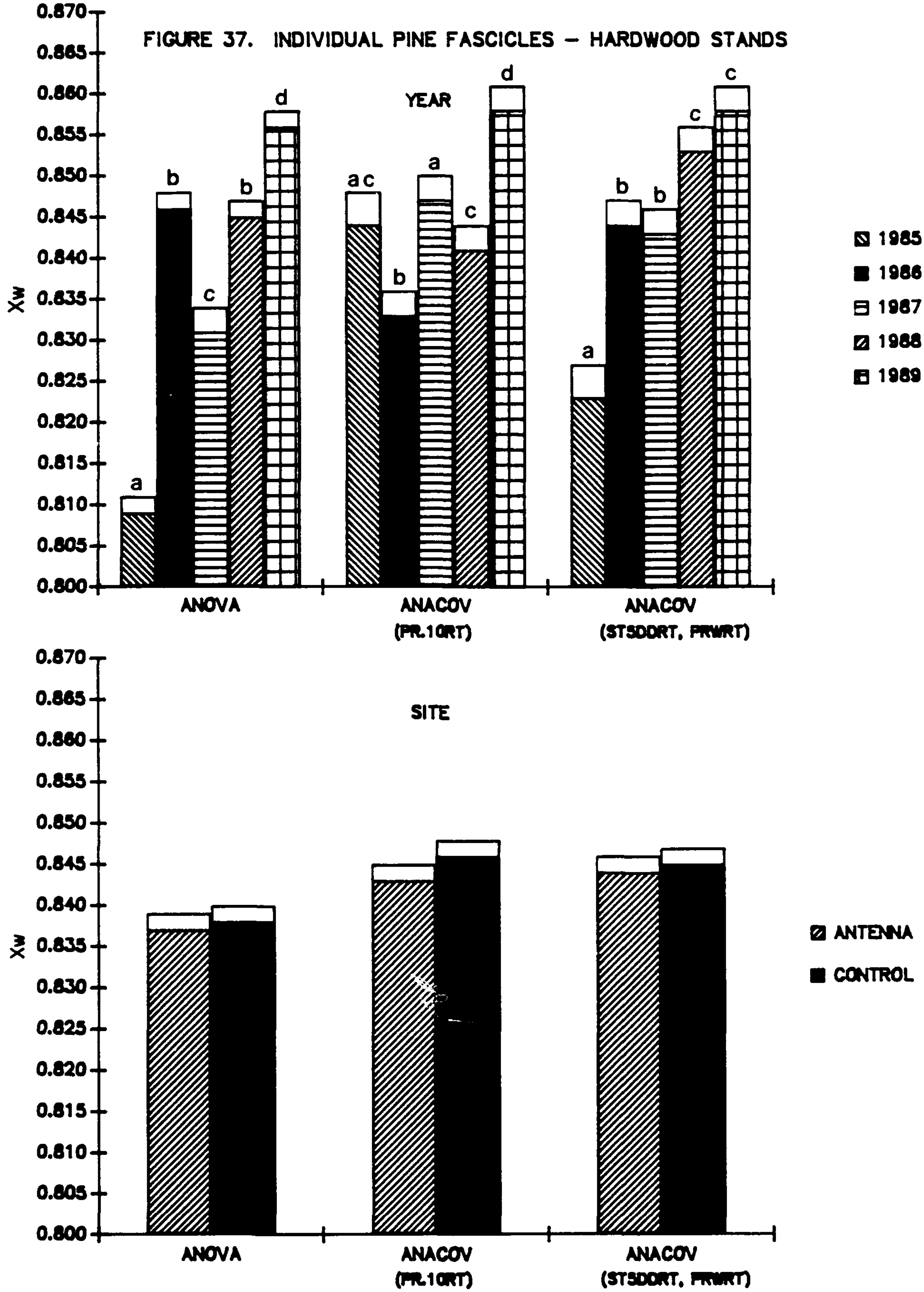


FIGURE 37. INDIVIDUAL PINE FASCICLES – HARDWOOD STANDS

Table 74. Covariance analysis table for detection of differences in dry matter mass loss (arcsin square root of the proportion of initial mass remaining) from **Individual Oak** leaves in the three **Plantation** subunits, using one covariate: **PRWRT**, running total of precipitation.

Source of Variation	df	SS	Type III SS	F	Signif. of F	r^2
Model	13	64.88		484.28	0.0000	0.70
Year	4		11.44	277.46	0.0000	
Month	6		5.00	80.82	0.0000	
Plantation	2		0.00	0.17	0.8405	
PRWRT	1		0.48	47.01	0.0001	
Error	2713	27.96				
Corrected Total	2726	92.40				

Table 75. Adjusted means, standard errors, detectable differences, and significantly different pairs of means, based on the model analyzed in Table 76.

Source of Variation	Adjusted Mean[a]	Standard Error	Detectable Difference[b]	Significant Differences[c]						
Year					5	6	7	8		
1985	1.132	0.006	1.04	1985						
1986	1.133	0.005	0.86	1986						
1987	1.004	0.005	0.98	1987	*	*				
1988	1.000	0.005	0.98	1988	*	*				
1989	1.002	0.005	0.98	1989	*	*				
Month					1	2	3	4	5	6
May	1.232	0.009	1.43	May						
June	1.149	0.007	1.19	June	*					
July	1.093	0.006	1.08	July	*	*				
August	1.037	0.005	0.95	Aug	*	*	*			
September	0.983	0.006	1.20	Sept	*	*	*	*		
October	0.956	0.008	1.64	Oct	*	*	*	*	*	
November	0.929	0.010	2.11	Nov	*	*	*	*	*	*
Plantation					G	A	C			
Ground	1.053	0.003	0.56	Ground						
Antenna	1.055	0.003	0.56	Antenna						
Control	1.054	0.003	0.56	Control						

a/ mean of transformed data
b/ estimated shift in the sample mean which would be detected 95 percent of the time (α = .05), calculated as $t_{.05,n}$*S.E./Mean, and expressed as a percentage of the sample mean
c/ α = .05, least squares means pairwise comparisons

Table 76. Covariance analysis table (including year * plantation interaction) for detection of differences in dry matter mass loss (arcsin square root of the proportion of initial mass remaining) from **Individual Oak** leaves in the three **Plantation** subunits, using one covariate: **PRWRT**, running total of precipitation.

Source of Variation	df	SS	Type III SS	F	Signif. of F	r^2
Model	21	65.11		302.49	0.0000	0.70
Year	4		11.43	278.74	0.0000	
Month	6		4.54	73.82	0.0000	
Plantation	2		0.00	0.08	0.9192	
Year*Plantation	8		0.23	2.83	0.0040	
PRWRT	1		0.47	45.51	0.0001	
Error	2705	27.73				
Corrected Total	2726	92.84				

Table 77. Adjusted means, standard errors, detectable differences, and significantly different pairs of means, based on the model analyzed in Table 78.

Source of Variation	Adjusted Mean[a]	Standard Error	Detectable Difference[b]	Significant Differences[c]						
Year					5	6	7	8		
1985	1.134	0.006	1.04	1985						
1986	1.132	0.006	1.04	1986						
1987	1.004	0.005	0.98	1987	*	*				
1988	0.999	0.005	0.98	1988	*	*				
1989	1.001	0.005	0.98	1989	*	*				
Month					1	2	3	4	5	6
May	1.229	0.010	1.58	May						
June	1.147	0.008	1.37	June	*					
July	1.092	0.007	1.26	July	*	*				
August	1.037	0.005	0.95	Aug	*	*	*			
September	0.984	0.006	1.20	Sept	*	*	*	*		
October	0.958	0.081	1.64	Oct	*	*	*	*	*	
November	0.932	0.011	2.31	Nov	*	*	*	*	*	*
Plantation						G	A	C		
Ground	1.054	0.003	0.56	Ground						
Antenna	1.055	0.003	0.56	Antenna						
Control	1.054	0.004	0.74	Control						

a/ mean of transformed data
b/ estimated shift in the sample mean which would be detected 95 percent of the time ($\alpha = .05$), calculated as $t_{.05,n}$*S.E./Mean, and expressed as a percentage of the sample mean
c/ $\alpha = .05$, least squares means pairwise comparisons

Table 78. Covariance analysis table for detection of differences in dry matter mass loss (arcsin square root of the proportion of initial mass remaining) from **Individual Oak** leaves in the three **Plantation** subunits, using two covariates: 1) **ST5DDRT**, running total of soil temperature degree days (5 cm below ground level; 4.4°C basis), and 2) **PRWRT**, running total of precipitation.

Source of Variation	df	SS	Type III SS	F	Signif. of F	r^2
Model	14	64.97		451.66	0.0000	0.70
Year	4		11.43	278.05	0.0000	
Month	6		0.70	11.40	0.0001	
Plantation	2		0.02	0.88	0.4137	
ST5DDRT	1		0.46	8.98	0.0027	
PRWRT	1		0.09	44.34	0.0001	
Error	2712	27.87				
Corrected Total	2726	92.84				

Table 79. Adjusted means, standard errors, detectable differences, and significantly different pairs of means, based on the model analyzed in Table 80.

Source of Variation	Adjusted Mean[a]	Standard Error	Detectable Difference[b]	Significant Differences[c]						
Year					5	6	7	8		
1985	1.127	0.006	1.04	1985						
1986	1.136	0.005	0.86	1986						
1987	1.004	0.005	0.98	1987	*	*				
1988	1.001	0.005	0.98	1988	*	*				
1989	1.000	0.005	0.98	1989	*	*				
Month					1	2	3	4	5	6
May	1.145	0.030	5.14	May						
June	1.084	0.023	4.16	June	*					
July	1.060	0.013	2.40	July	*					
August	1.041	0.005	0.94	Aug	*					
September	1.025	0.015	2.87	Sept	*					
October	1.021	0.023	4.42	Oct	*					
November	1.001	0.026	5.09	Nov	*					*
Plantation					G	A	C			
Ground	1.050	0.004	0.75	Ground						
Antenna	1.056	0.003	0.56	Antenna						
Control	1.055	0.003	0.56	Control						

a/ mean of transformed data
b/ estimated shift in the sample mean which would be detected 95 percent of the time (α = .05), calculated as $t_{.05,n}$*S.E./Mean, and expressed as a percentage of the sample mean
c/ α = .05, least squares means pairwise comparisons

Table 80. Covariance analysis table (including year * plantation interaction) for detection of differences in dry matter mass loss (arcsin square root of the proportion of initial mass remaining) from **Individual Oak** leaves in the three **Plantation** subunits, using two covariates: 1) **ST5DDRT**, running total of soil temperature degree days (5 cm below ground level; 4.4°C basis), and 2) **PRWRT**, running total of precipitation.

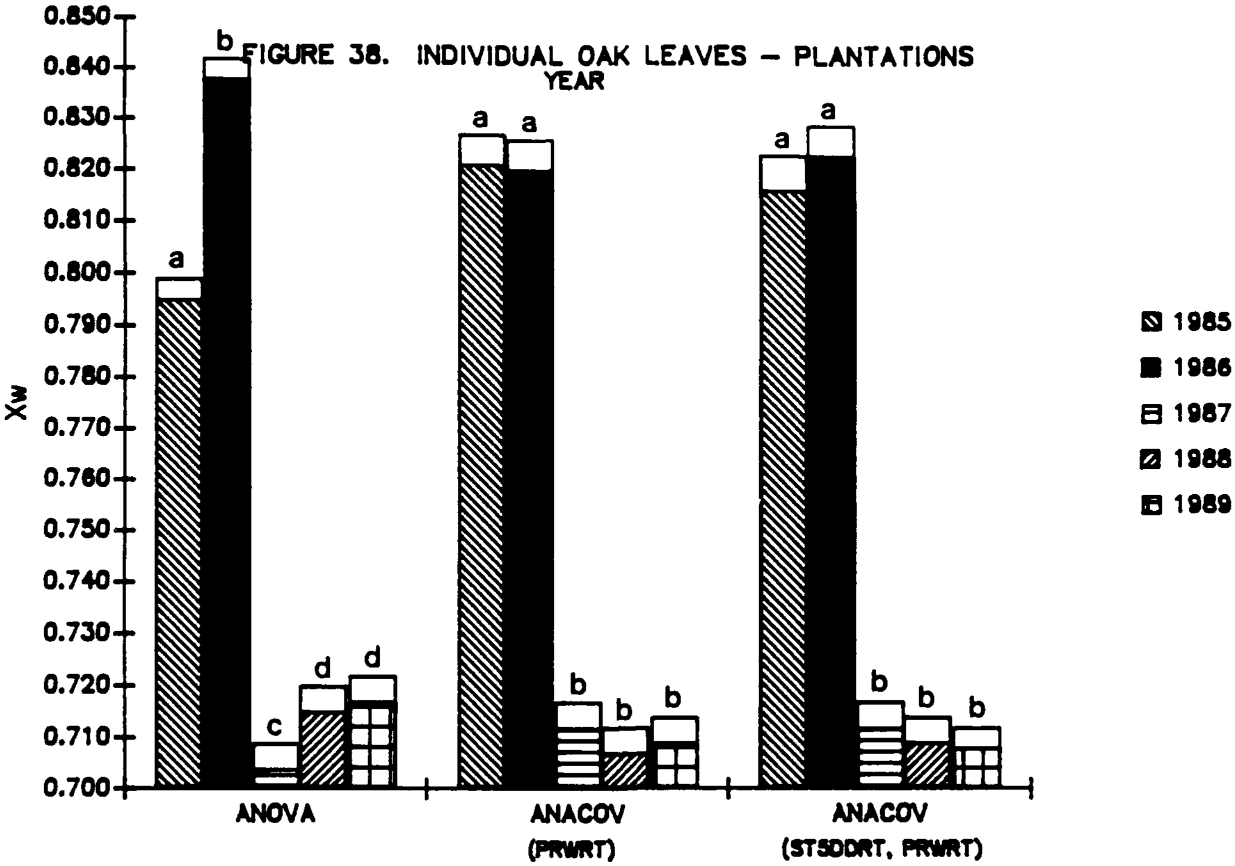
Source of Variation	df	SS	Type III SS	F	Signif. of F	r^2
Model	22	65.22		290.27	0.0000	0.70
Year	4		11.42	279.45	0.0000	
Month	6		0.68	11.14	0.0001	
Plantation	2		0.01	0.72	0.4879	
Year*Plantation	8		0.25	3.05	0.0020	
ST5DDRT	1		0.44	42.78	0.0001	
PRWRT	1		0.11	10.76	0.0011	
Error	2704	27.62				
Corrected Total	2726	92.84				

Table 81. Adjusted means, standard errors, detectable differences, and significantly different pairs of means, based on the model analyzed in Table 82.

Source of Variation	Adjusted Mean[a]	Standard Error	Detectable Difference[b]	Significant Differences[c]						
Year					5	6	7	8		
1985	1.128	0.007	1.22	1985						
1986	1.136	0.005	0.04	1986						
1987	1.004	0.005	0.98	1987	*	*				
1988	1.001	0.005	0.98	1988	*	*				
1989	0.999	0.005	0.98	1989	*	*				
Month					1	2	3	4	5	6
May	1.128	0.032	5.56	May						
June	1.072	0.024	4.39	June	*					
July	1.053	0.013	2.42	July	*					
August	1.041	0.005	0.94	Aug	*					
September	1.033	0.016	3.04	Sept	*					
October	1.034	0.025	4.74	Oct						
November	1.016	0.028	5.40	Nov						*
Plantation					G	A	C			
Ground	1.050	0.004	0.75	Ground						
Antenna	1.056	0.003	0.56	Antenna						
Control	1.054	0.004	0.74	Control						

a/ mean of transformed data
b/ estimated shift in the sample mean which would be detected 95 percent of the time ($\alpha = .05$), calculated as $t_{.05,n}$*S.E./Mean, and expressed as a percentage of the sample mean
c/ $\alpha = .05$, least squares means pairwise comparisons

FIGURE 38. INDIVIDUAL OAK LEAVES - PLANTATIONS



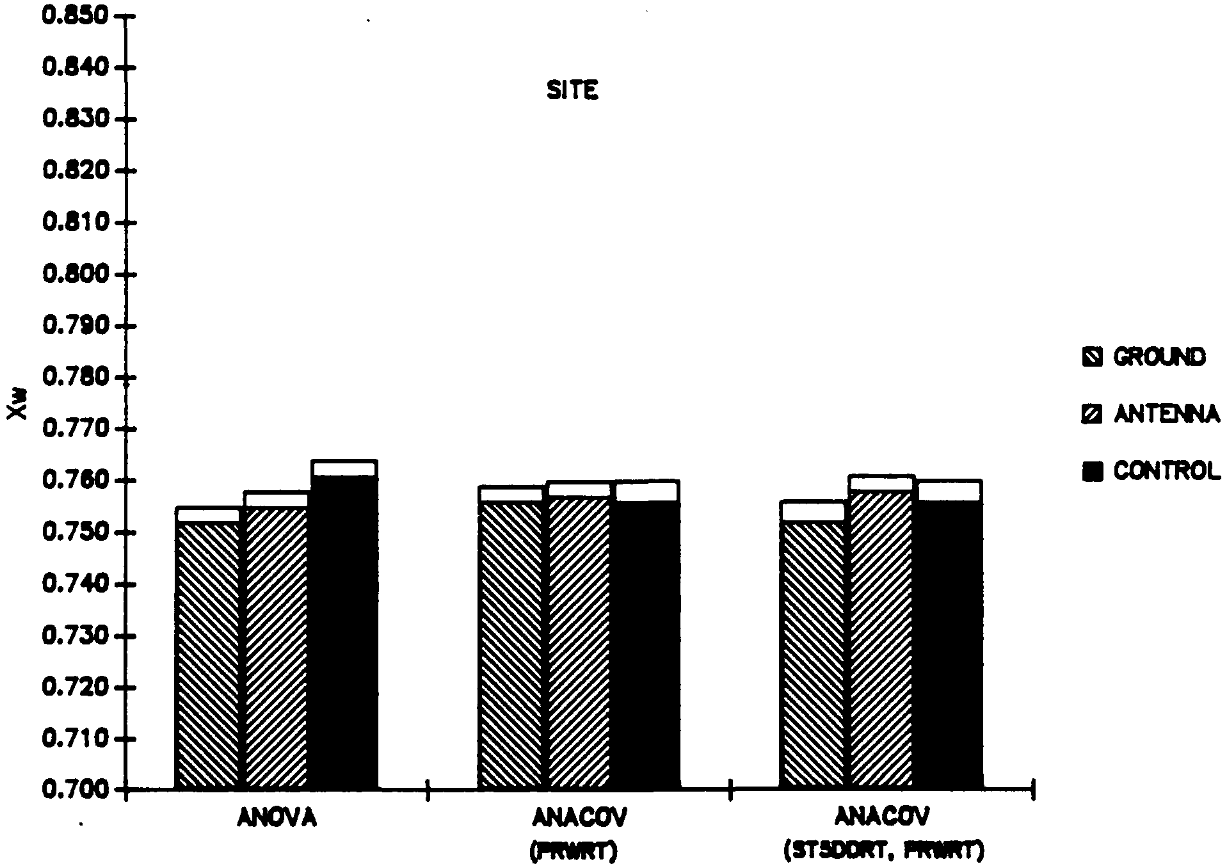


Table 82. Covariance analysis table for detection of differences in dry matter mass loss (arcsin square root of the proportion of initial mass remaining) from **Individual Oak** leaves in the two **Hardwood Stand** subunits, using two covariates: 1) **DENSITY**, initial leaf density, and 2) **PRWRT**, running total of precipitation.

Source of Variation	df	SS	Type III SS	F	Signif. of F	r^2
Model	14	33.43		459.47	0.0000	0.77
Year	4		0.79	38.01	0.0001	
Month	7		2.66	73.25	0.0000	
Hardwood Stand	1		0.01	1.21	0.2716	
DENSITY	1		1.52	292.71	0.0001	
PRWRT	1		0.06	11.51	0.0007	
Error	1968	10.23				
Corrected Total	1982	43.66				

Table 83. Adjusted means, standard errors, detectable differences, and significantly different pairs of means, based on the model analyzed in Table 84.

Source of Variation	Adjusted Mean[a]	Standard Error	Detectable Difference[b]	Significant Differences[c]							
Year					5	6	7	8			
1985	1.135	0.005	0.86	1985							
1986	1.161	0.004	0.68	1986	*						
1987	1.141	0.004	0.69	1987		*					
1988	1.119	0.004	0.70	1988	*	*	*				
1989	1.100	0.004	0.71	1989	*	*	*	*			
Month					1	2	3	4	5	6	7
May	1.288	0.008	1.22	May							
June	1.248	0.007	1.10	June							
July	1.223	0.006	0.96	July	*	*					
August	1.172	0.005	0.84	Aug	*	*					
September	1.100	0.005	0.89	Sept	*	*	*	*			
October	1.038	0.006	1.13	Oct	*	*	*	*	*		
November	0.990	0.007	1.39	Nov	*	*	*	*	*	*	
December	0.995	0.010	1.97	Dec	*	*	*	*	*		*
Hardwood Stand					A	C					
Antenna	1.129	0.002	0.35	Antenna							
Control	1.133	0.002	0.35	Control							

a/ mean of transformed data
b/ estimated shift in the sample mean which would be detected 95 percent of the time ($\alpha = .05$), calculated as $t_{.05,n}$*S.E./Mean, and expressed as a percentage of the sample mean
c/ $\alpha = .05$, least squares means pairwise comparisons

Table 84. Covariance analysis table (including year * stand interaction) for detection of differences in dry matter mass loss (arcsin square root of the proportion of initial mass remaining) from **Individual Oak** leaves in the two **Hardwood Stand** subunits, using two covariates: 1) **DENSITY**, initial leaf density, and 2) **PRWRT**, running total of precipitation.

Source of Variation	df	SS	Type III SS	F	Signif. of F	r^2
Model	18	33.88		378.02	0.0000	0.78
Year	4		0.79	39.77	0.0001	
Month	7		2.27	65.01	0.0000	
Hardwood Stand	1		0.02	4.82	0.0283	
Year * Stand	4		0.45	22.54	0.0001	
DENSITY	1		1.52	305.86	0.0001	
PRWRT	1		0.06	11.23	0.0008	
Error	1964	9.78				
Corrected Total	1982	43.66				

Table 85. Adjusted means, standard errors, detectable differences, and significantly different pairs of means, based on the model analyzed in Table 86.

Source of Variation	Adjusted Mean[a]	Standard Error	Detectable Difference[b]	Significant Differences[c]							
Year					5	6	7	8			
1985	1.136	0.005	0.86	1985							
1986	1.161	0.004	0.68	1986	*						
1987	1.142	0.004	0.69	1987		*					
1988	1.119	0.004	0.70	1988	*	*	*				
1989	1.099	0.004	0.71	1989	*	*	*	*			
Month					1	2	3	4	5	6	7
May	1.287	0.008	1.22	May							
June	1.247	0.007	1.10	June	*						
July	1.222	0.006	0.96	July	*	*					
August	1.171	0.005	0.84	Aug	*	*	*				
September	1.096	0.005	0.89	Sept	*	*	*	*			
October	1.039	0.006	1.13	Oct	*	*	*	*	*		
November	0.991	0.008	1.58	Nov	*	*	*	*	*	*	
December	0.997	0.010	1.97	Dec	*	*	*	*	*	*	*
Hardwood Stand					A	C					
Antenna	1.127	0.002	0.35	Antenna							
Control	1.135	0.002	0.35	Control	*						

a/ mean of transformed data

b/ estimated shift in the sample mean which would be detected 95 percent of the time (α = .05), calculated as $t_{.05,n}$*S.E./Mean, and expressed as a percentage of the sample mean

c/ α = .05, least squares means pairwise comparisons

generally significant. Detectable differences were well below 1 percent for years and stands, and below 2 percent for months. Though the year by site interaction was highly significant, detectable differences and treatment level means were only slightly affected. The pattern of significant differences among years was unaffected, but the difference between the two stands became significant.

Tables 86 - 89 present the ANACOV for the hardwood stands, using DENSITY, PR.01RT, and PRWRT as covariates. No significant difference was detected between the two hardwood stands. Comparing years, decomposition proceeded fastest in 1988 and 1989 (n.s.d.), and slowest in 1985 through 1987 (n.s.d.). Monthly progress in decomposition was generally significant. Detectable differences were approximately 1 percent for years, well below 1 percent for sites, and below 3.5 percent for months. Though the year by site interaction was highly significant, detectable differences and treatment level means were only slightly affected. The pattern of significant differences among years was unaffected, but again the difference between the two stands became significant. Figure 39 depicts the results of ANOVA and ANACOV for individual oak leaves in the hardwood stands.

ANACOV Results - Bulk Leaf Litter Samples

Bulk Pine Needle Litter

For the plantations, Tables 90 - 93 present the ANACOV models using PR.1RT as the only covariate. Decomposition proceeded faster at the ground and control plantations (n.s.d.) than at the antenna plantation. Decomposition proceeded fastest in 1985, 1986 and 1989 (n.s.d.), and slowest in 1987. Decomposition in 1988 proceeded at an intermediate rate. Monthly progress in decomposition was generally significant. Detectable differences were well below 1 percent for years and plantations, and below 2 percent for months. The year by site interaction was not significant ($p = 0.0628$), had little effect on treatment means or detectable differences, and did not affect the outcome of multiple comparisons. Figure 40 depicts the results of ANOVA and ANACOV for bulk pine samples in the plantations.

For the hardwood stands, Tables 94 - 97 present the ANACOV models using PR.1RT as sole covariate. Decomposition proceeded faster in the antenna stand than in the control stand. Comparing years, decomposition proceeded fastest in 1985, 1986 and 1989 (n.s.d.), and slowest in 1987 and 1988 (n.s.d.). Decomposition failed to progress during October and November. Detectable differences were well below 1 percent for year and site, and below 2.5 percent for month. The year by site interaction was highly significant, but had little effect on treatment means or detectable differences, and did not affect the results of multiple comparisons. Figure 41 depicts the results of ANOVA and ANACOV for bulk pine samples in the hardwood stands.

Table 86. Covariance analysis table for detection of differences in dry matter mass loss (arcsin square root of the proportion of initial mass remaining) from **Individual Oak** leaves in the two **Hardwood Stand** subunits, using three covariates: 1) **DENSITY**, initial leaf density, 2) **PR.01RT**, running total of days with precipitation events totalling at least 0.01 inch, and 3) **PRWRT**, running total of precipitation.

Source of Variation	df	SS	Type III SS	F	Signif. of F	r^2
Model	155	33.44		428.95	0.0000	0.77
Year	4		0.76	36.46	0.0001	
Month	7		0.76	20.76	0.0001	
Hardwood Stand	1		0.01	2.02	0.1553	
DENSITY	1		1.52	292.70	0.0001	
PR.01RT	1		0.01	1.16	0.2822	
PRWRT	1		0.02	3.48	0.0623	
Error	1967	10.22				
Corrected Total	1982	43.66				

Table 87. Adjusted means, standard errors, detectable differences, and significantly different pairs of means, based on the model analyzed in Table 88.

Source of Variation	Adjusted Mean[a]	Standard Error	Detectable Difference[b]	Significant Differences[c]							
Year					5	6	7	8			
1985	1.138	0.006	1.03	1985							
1986	1.158	0.005	0.85	1986							
1987	1.146	0.006	1.03	1987							
1988	1.116	0.005	0.88	1988	*	*	*				
1989	1.102	0.005	0.89	1989	*	*	*				
Month					1	2	3	4	5	6	7
May	1.273	0.016	2.46	May							
June	1.273	0.012	1.90	June	*						
July	1.216	0.008	1.29	July	*	*					
August	1.169	0.005	0.84	Aug	*	*	*				
September	1.098	0.005	0.89	Sept	*	*	*	*			
October	1.046	0.009	1.69	Oct	*	*	*	*	*		
November	1.004	0.015	2.93	Nov	*	*	*	*	*	*	
December	1.011	0.018	3.49	Dec	*	*	*	*	*	*	
Hardwood Stand					A	C					
Antenna	1.129	0.002	0.35	Antenna							
Control	1.134	0.003	0.52	Control							

a/ mean of transformed data
b/ estimated shift in the sample mean which would be detected 95 percent of the time (α = .05), calculated as $t_{.05,n}$*S.E./Mean, and expressed as a percentage of the sample mean
c/ α = .05, least squares means pairwise comparisons

Table 88. Covariance analysis table (including year * stand interaction) for detection of differences in dry matter mass loss (arcsin square root of the proportion of initial mass remaining) from **Individual Oak** leaves in the two **Hardwood Stand** subunits, using three covariates: 1) **DENSITY**, initial leaf density, 2) **PR.01RT**, running total of days with precipitation events totalling at least 0.01 inch, and 3) **PRWRT**, running total of precipitation.

Source of Variation	df	SS	Type III SS	F	Signif. of F	r^2
Model	19	33.90		359.19	0.0000	0.78
Year	4		0.76	38.30	0.0001	
Month	7		0.64	18.50	0.0001	
Hardwood Stand	1		0.05	9.17	0.0025	
Year * Stand	4		0.47	23.61	0.0001	
DENSITY	1		1.52	305.55	0.0001	
PR.01RT	1		0.00	0.29	0.5882	
PRWRT	1		0.03	5.30	0.0008	
Error	1963	9.75				
Corrected Total	1982	43.66				

Table 89. Adjusted means, standard errors, detectable differences, and significantly different pairs of means, based on the model analyzed in Table 90.

Source of Variation	Adjusted Mean[a]	Standard Error	Detectable Difference[b]	Significant Differences[c]							
Year					5	6	7	8			
1985	1.142	0.006	1.03	1985							
1986	1.154	0.005	0.85	1986							
1987	1.152	0.006	1.02	1987							
1988	1.111	0.005	0.88	1988	*	*	*				
1989	1.105	0.005	0.89	1989	*	*	*				
Month					1	2	3	4	5	6	7
May	1.255	0.016	2.50	May							
June	1.224	0.012	1.92	June	*						
July	1.209	0.008	1.30	July	*	*					
August	1.165	0.005	0.84	Aug	*	*	*				
September	1.101	0.005	0.89	Sept	*	*	*	*			
October	1.055	0.009	1.67	Oct	*	*	*	*	*		
November	1.022	0.015	2.88	Nov	*	*	*	*	*	*	
December	1.032	0.018	3.42	Dec	*	*	*	*	*	*	*
Hardwood Stand					A	C					
Antenna	1.127	0.002	0.35	Antenna							
Control	1.139	0.003	0.52	Control	*						

a/ mean of transformed data
b/ estimated shift in the sample mean which would be detected 95 percent of the time (α = .05), calculated as $t_{.05,n}$*S.E./Mean, and expressed as a percentage of the sample mean
c/ α = .05, least squares means pairwise comparisons

FIGURE 39. INDIVIDUAL OAK LEAVES – HARDWOOD STANDS

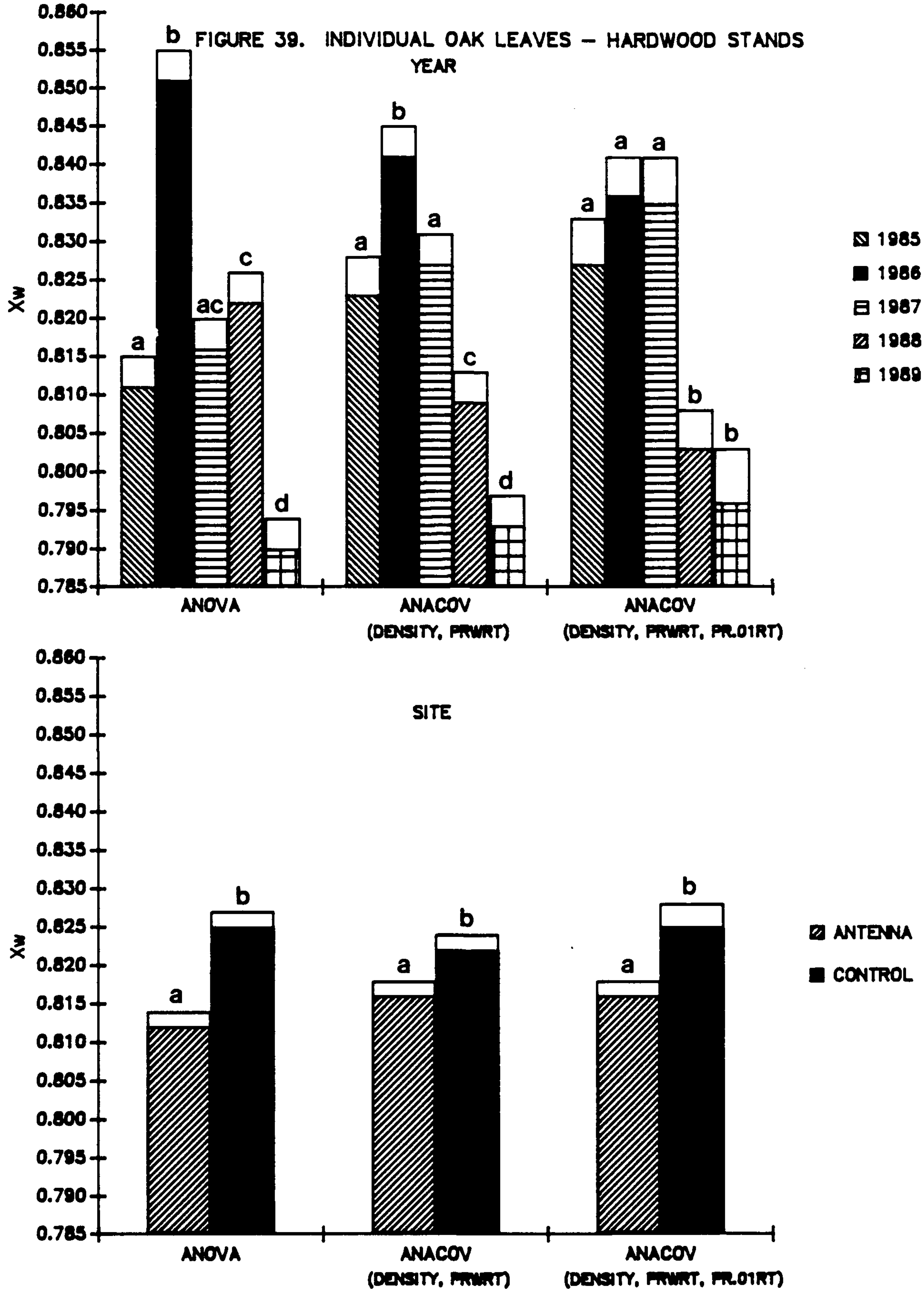


Table 90. Covariance analysis table for detection of differences in dry matter mass loss (arcsin square root of the proportion of initial mass remaining) from **Bulk Pine** needle samples in the three **Plantation** subunits, using one covariate: **PR.1RT**, running total of days with precipitation events totalling at least 0.10 inch.

Source of Variation	df	SS	Type III SS	F	Signif. of F	r^2
Model	13	5.30		369.27	0.0000	0.89
Year	4		0.15	34.61	0.0001	
Month	6		0.13	20.20	0.0001	
Plantation	2		0.06	25.06	0.0001	
PR.1RT	1		0.05	40.87	0.0001	
Error	616	0.68				
Corrected Total	629	5.98				

Table 91. Adjusted means, standard errors, detectable differences, and significantly different pairs of means, based on the model analyzed in Table 92.

Source of Variation	Adjusted Mean[a]	Standard Error	Detectable Difference[b]	Significant Differences[c]						
Year					5	6	7	8		
1985	1.144	0.005	0.86	1985						
1986	1.132	0.004	0.69	1986						
1987	1.178	0.003	0.50	1987	*	*				
1988	1.149	0.003	0.51	1988		*	*			
1989	1.135	0.003	0.52	1989			*	*		
Month					1	2	3	4	5	6
May	1.221	0.009	1.44	May						
June	1.196	0.007	1.15	June	*					
July	1.182	0.005	0.83	July	*	*				
August	1.155	0.004	0.68	Aug	*	*	*			
September	1.112	0.005	0.88	Sept	*	*	*	*		
October	1.081	0.007	1.27	Oct	*	*	*	*	*	
November	1.085	0.010	1.81	Nov	*	*	*	*	*	*
Plantation					G	A	C			
Ground	1.140	0.002	0.34	Ground						
Antenna	1.161	0.002	0.34	Antenna	*					
Control	1.142	0.002	0.34	Control		*				

a/ mean of transformed data
b/ estimated shift in the sample mean which would be detected 95 percent of the time (α = .05), calculated as $t_{.05,n}$*S.E./Mean, and expressed as a percentage of the sample mean
c/ α = .05, least squares means pairwise comparisons

Table 92. Covariance analysis table (including year * plantation interaction) for detection of differences in dry matter mass loss (arcsin square root of the proportion of initial mass remaining) from **Bulk Pine** needle samples in the three **Plantation** subunits, using one covariate: **PR.1RT**, running total of days with precipitation events totalling at least 0.10 inch.

Source of Variation	df	SS	Type III SS	F	Signif. of F	r^2
Model	21	5.32		231.88	0.0000	0.89
Year	4		0.15	34.65	0.0001	
Month	6		0.12	18.99	0.0001	
Plantation	2		0.06	25.33	0.0001	
Year*Plantation	8		0.02	1.87	0.0628	
PR.1RT	1		0.03	31.05	0.0001	
Error	608	0.66				
Corrected Total	629	5.98				

Table 93. Adjusted means, standard errors, detectable differences, and significantly different pairs of means, based on the model analyzed in Table 94.

Source of Variation	Adjusted Mean[a]	Standard Error	Detectable Difference[b]	Significant Differences[c]						
Year					5	6	7	8		
1985	1.143	0.005	0.86	1985						
1986	1.133	0.004	0.69	1986						
1987	1.177	0.003	0.50	1987	*	*				
1988	1.150	0.004	0.68	1988		*	*			
1989	1.135	0.003	0.52	1989			*	*		
Month					1	2	3	4	5	6
May	1.224	0.009	1.44	May						
June	1.197	0.007	1.15	June	*					
July	1.183	0.005	0.83	July	*	*				
August	1.155	0.004	0.68	Aug	*	*	*			
September	1.111	0.005	0.88	Sept	*	*	*	*		
October	1.080	0.008	1.45	Oct	*	*	*	*	*	
November	1.083	0.011	1.99	Nov	*	*	*	*	*	*
Plantation						G	A	C		
Ground	1.140	0.002	0.34	Ground						
Antenna	1.161	0.002	0.34	Antenna		*				
Control	1.142	0.002	0.34	Control			*			

a/ mean of transformed data
b/ estimated shift in the sample mean which would be detected 95 percent of the time (α = .05), calculated as $t_{.05,n}$*S.E./Mean, and expressed as a percentage of the sample mean
c/ α = .05, least squares means pairwise comparisons

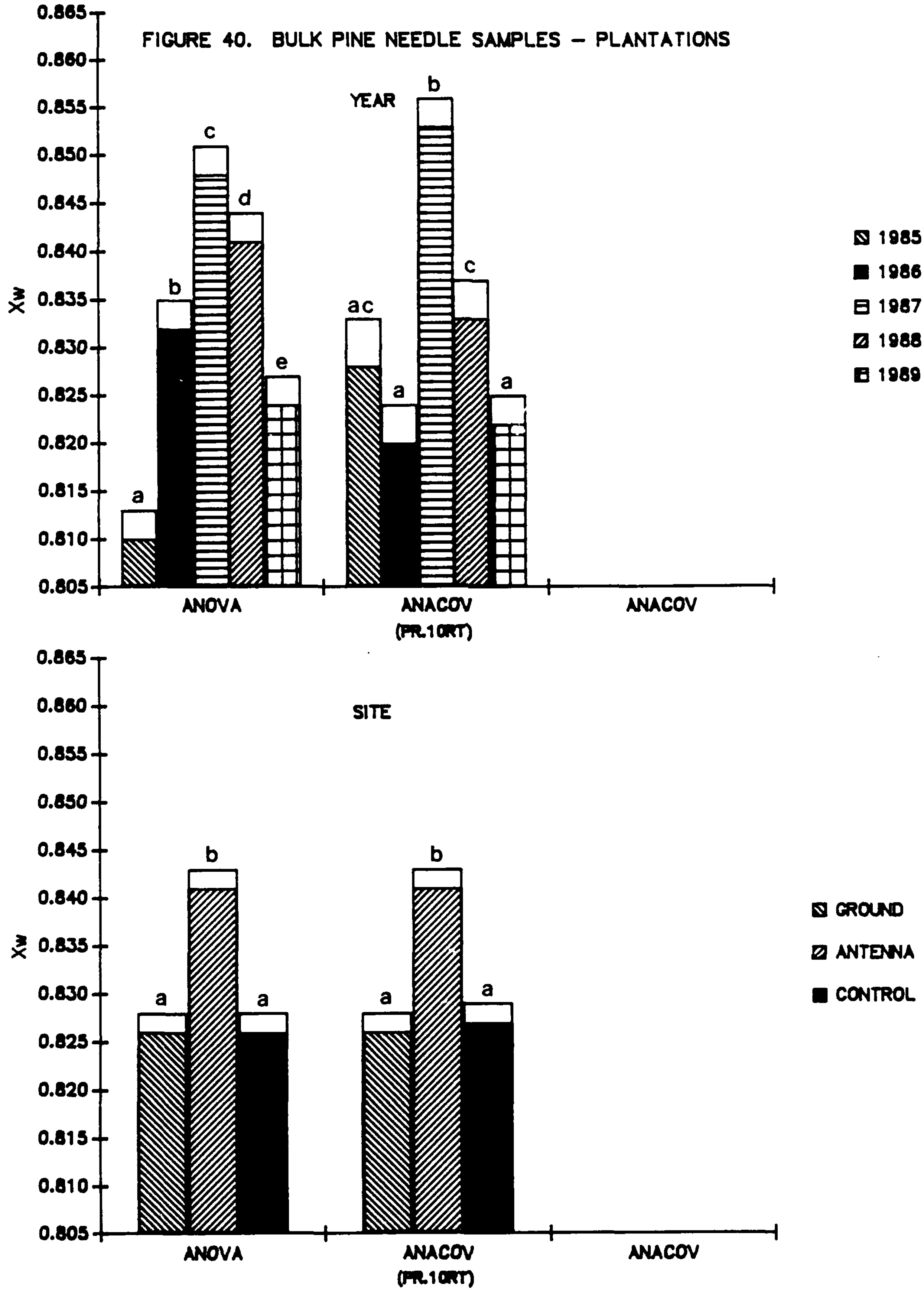


FIGURE 40. BULK PINE NEEDLE SAMPLES – PLANTATIONS

Table 94. Covariance analysis table for detection of differences in dry matter mass loss (arcsin square root of the proportion of initial mass remaining) from **Bulk Pine** needle samples in the two **Hardwood Stand** subunits, using one covariate: **PR.1RT**, running total of days with precipitation events totalling at least 0.10 inch.

Source of Variation	df	SS	Type III SS	F	Signif. of F	r^2
Model	13	4.75		390.22	0.0000	0.92
Year	4		0.06	16.05	0.0001	
Month	7		0.14	22.07	0.0001	
Hardwood Stand	2		0.01	13.14	0.0032	
PR.1RT	1		0.05	55.65	0.0001	
Error	440	0.41				
Corrected Total	453	5.16				

Table 95. Adjusted means, standard errors, detectable differences, and significantly different pairs of means, based on the model analyzed in Table 96.

Source of Variation	Adjusted Mean[a]	Standard Error	Detectable Difference[b]	Significant Differences[c]							
Year					5	6	7	8			
1985	1.125	0.005	0.87	1985							
1986	1.132	0.004	0.69	1986							
1987	1.154	0.004	0.68	1987	*	*					
1988	1.154	0.004	0.68	1988	*	*					
1989	1.134	0.003	0.52	1989			*	*			
Month					1	2	3	4	5	6	7
May	1.217	0.011	1.77	May							
June	1.192	0.009	1.48	June	*						
July	1.181	0.006	1.00	July	*						
August	1.155	0.004	0.68	Aug	*	*	*				
September	1.103	0.004	0.71	Sept	*	*	*	*			
October	1.085	0.007	1.26	Oct	*	*	*	*	*		
November	1.090	0.010	1.80	Nov	*	*	*	*			
December	1.097	0.013	2.32	Dec	*	*	*	*		*	
Hardwood Stand					A	C					
Antenna	1.135	0.002	0.35	Antenna							
Control	1.145	0.002	0.34	Control	*						

a/ mean of transformed data

b/ estimated shift in the sample mean which would be detected 95 percent of the time (α = .05), calculated as $t_{.05,n}$*S.E./Mean, and expressed as a percentage of the sample mean

c/ α = .05, least squares means pairwise comparisons

Table 96. Covariance analysis table (including year * stand interaction) for detection of differences in dry matter mass loss (arcsin square root of the proportion of initial mass remaining) from **Bulk Pine** needle samples in the two **Hardwood Stand** subunits, using one covariate: **PR.1RT**, running total of days with precipitation events totalling at least 0.10 inch.

Source of Variation	df	SS	Type III SS	F	Signif. of F	r^2
Model	13	4.79		331.55	0.0000	0.93
Year	4		0.06	17.57	0.0001	
Month	7		0.13	21.13	0.0001	
Hardwood Stand	1		0.01	16.74	0.0001	
Year * Stand	4		0.04	12.17	0.0001	
PR.1RT	1		0.05	56.93	0.0001	
Error	436	0.37				
Corrected Total	453	5.16				

Table 97. Adjusted means, standard errors, detectable differences, and significantly different pairs of means, based on the model analyzed in Table 98.

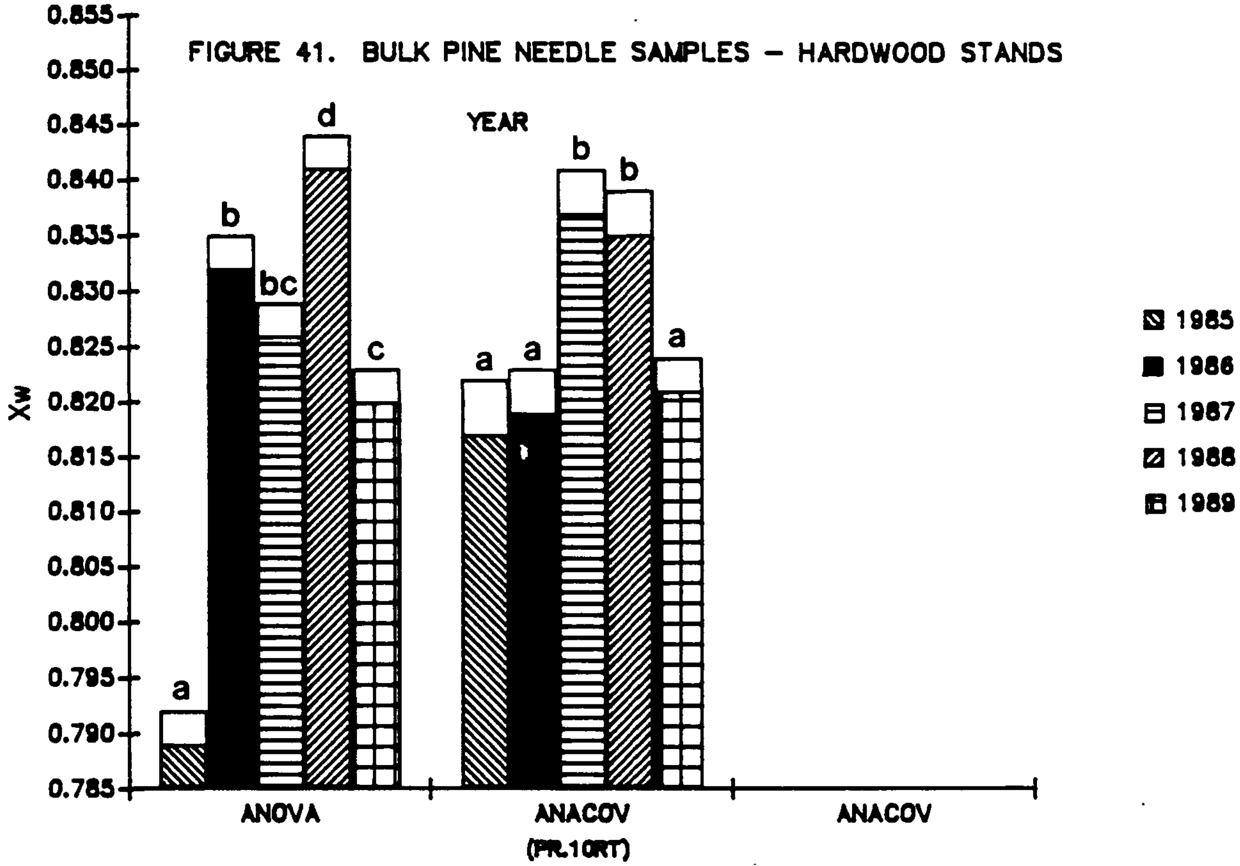
Source of Variation	Adjusted Mean[a]	Standard Error	Detectable Difference[b]	Significant Differences[c]							
Year					5	6	7	8			
1985	1.129	0.005	0.87	1985							
1986	1.131	0.004	0.69	1986							
1987	1.155	0.004	0.68	1987	*	*					
1988	1.153	0.004	0.68	1988	*	*					
1989	1.134	0.003	0.52	1989			*	*			
Month					1	2	3	4	5	6	7
May	1.209	0.011	1.78	May							
June	1.186	0.009	1.49	June	*						
July	1.177	0.006	1.00	July	*						
August	1.153	0.004	0.68	Aug	*	*	*				
September	1.105	0.004	0.71	Sept	*	*	*	*			
October	1.090	0.007	1.26	Oct	*	*	*	*	*		
November	1.097	0.010	1.79	Nov	*	*	*	*			
December	1.106	0.013	2.30	Dec	*	*	*	*		*	
Hardwood Stand					A	C					
Antenna	1.135	0.002	0.35	Antenna							
Control	1.146	0.002	0.34	Control	*						

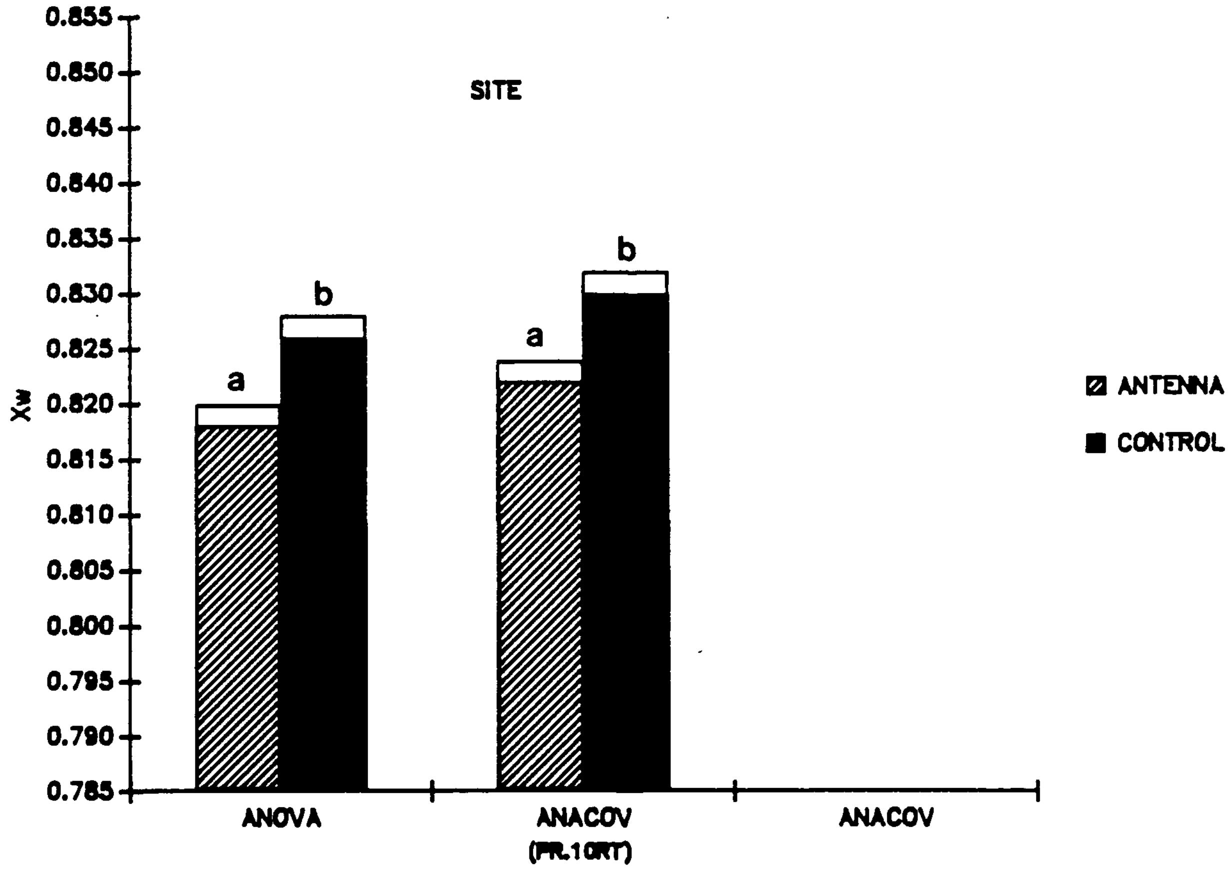
a/ mean of transformed data

b/ estimated shift in the sample mean which would be detected 95 percent of the time (α = .05), calculated as $t_{.05,n}$*S.E./Mean, and expressed as a percentage of the sample mean

c/ α = .05, least squares means pairwise comparisons

FIGURE 41. BULK PINE NEEDLE SAMPLES – HARDWOOD STANDS





Bulk Oak Leaf Litter

For the plantation data, Tables 98 - 101 present the ANACOV models using ATDDRT and PRWRT as covariates. Decomposition proceeded faster in the ground and antenna plantations than in the control plantation. Comparing years, decomposition proceeded fastest in 1989 and slowest in 1986 and 1987 (n.s.d.). Decomposition during 1985 and 1988 proceeded at an intermediate rate (n.s.d.). Decomposition progressed significantly from month to month. Detectable differences were well below 1.5 percent for years, well below 1 percent for plantations, but as high as 5 percent for some months. The year by site interaction was barely significant ($p = 0.0429$), but affected treatment means and detectable differences only slightly, and had no effect on multiple comparison results.

Tables 102 - 105 present the plantation ANACOV using ATDDRT, PR.1RT, and PR.01RT as covariates. Decomposition again proceeded faster in the ground and antenna plantations (n.s.d.) than in the control plantation. Decomposition proceeded fastest in 1989 and slowest in 1987. Monthly decomposition progress was not significant. Detectable differences were below 1.5 percent for years, well below 1 percent for sites, but nearly 6 percent for some months. The year by site interaction was significant, and had very little effect on treatment means and detectable differences, but did explain the marginally significant difference between 1985 and 1987. Figure 42 depicts the results of ANOVA and ANACOV for the bulk oak samples in the plantations.

For the hardwood stands, Tables 106 - 109 present the ANACOV models using PR.1RT and PRWRT as covariates. No significant difference was detected between the two hardwood stands. Decomposition proceeded fastest in 1989, and slowest in 1986 and 1987 (n.s.d.). Decomposition in 1985 and 1988 proceeded at an intermediate rate (n.s.d.). Monthly decomposition progress was significant mainly during mid-season. Detectable differences were below 1.5 percent for years, well below 1 percent for sites, but approaching or exceeding 3 percent for several months. The year by stand interaction was highly significant, but had little effect on treatment means or detectable differences, and did not affect the outcome of multiple comparisons. Figure 43 depicts the results of ANOVA and ANACOV for bulk oak samples in the hardwood stands, with the year by site interaction included.

Bulk Maple Leaf Litter

For the plantation data, Tables 110 - 113 present the ANACOV models using PRWRT as sole covariate. Decomposition proceeded faster in the ground and antenna plantations (n.s.d.) than in the control plantation. Decomposition proceeded fastest in 1985, slowest in 1989, and faster in 1988 than in 1986 or 1987 (n.s.d.). Monthly progress in decomposition was significant. Detectable differences were well below 2 percent for years, below 1 percent for sites, and well below 3 percent for months. The year by site interaction was highly significant, but did not

Table 98. Covariance analysis table for detection of differences in dry matter mass loss (arcsin square root of the proportion of initial mass remaining) from **Bulk Oak** leaf samples in the three **Plantation** subunits, using two covariates: 1) **ATDDRT**, running total of air temperature degree days (4.4°C basis), and 2) **PRWRT**, running total of precipitation.

Source of Variation	df	SS	Type III SS	F	Signif. of F	r^2
Model	14	7.87		205.38	0.0000	0.82
Year	4		0.27	24.80	0.0001	
Month	6		0.07	4.55	0.0002	
Plantation	2		0.03	5.94	0.0028	
ATDDRT	1		0.00	1.04	0.3090	
PRWRT	1		0.01	5.44	0.0200	
Error	611	1.67				
Corrected Total	625	9.54				

Table 99. Adjusted means, standard errors, detectable differences, and significantly different pairs of means, based on the model analyzed in Table 100.

Source of Variation	Adjusted Mean[a]	Standard Error	Detectable Difference[b]	Significant Differences[c]						
Year					5	6	7	8		
1985	1.140	0.007	1.20	1985						
1986	1.162	0.006	1.01	1986						
1987	1.165	0.005	0.84	1987	*					
1988	1.143	0.005	0.86	1988		*	*			
1989	1.106	0.005	0.89	1989	*	*	*	*		
Month					1	2	3	4	5	6
May	1.256	0.030	4.68	May						
June	1.216	0.023	3.71	June	*					
July	1.185	0.013	2.15	July	*	*				
August	1.150	0.006	1.02	Aug	*	*	*			
September	1.100	0.016	2.85	Sept	*	*	*	*		
October	1.061	0.023	4.25	Oct	*	*	*	*	*	
November	1.033	0.026	4.93	Nov	*	*	*	*	*	*
Plantation					G	A	C			
Ground	1.134	0.004	0.69	Ground						
Antenna	1.140	0.004	0.69	Antenna						
Control	1.155	0.004	0.68	Control	*	*				

a/ mean of transformed data
b/ estimated shift in the sample mean which would be detected 95 percent of the time (α = .05), calculated as $t_{.05,n}$*S.E./Mean, and expressed as a percentage of the sample mean
c/ α = .05, least squares means pairwise comparisons

Table 100. Covariance analysis table (including year * plantation interaction) for detection of differences in dry matter mass loss (arcsin square root of the proportion of initial mass remaining) from **Bulk Oak** leaf samples in the three **Plantation** subunits, using two covariates: 1) **ATDDRT**, running total of air temperature degree days (4.4°C basis), and 2) **PRWRT**, running total of precipitation.

Source of Variation	df	SS	Type III SS	F	Signif. of F	r^2
Model	22	7.91		133.16	0.0000	0.83
Year	4		0.27	25.21	0.0001	
Month	6		0.07	4.47	0.0002	
Plantation	2		0.03	5.46	0.0045	
Year*Plantation	8		0.04	2.01	0.0429	
ATDDRT	1		0.00	0.72	0.3954	
PRWRT	1		0.01	5.04	0.0251	
Error	603	1.63				
Corrected Total	625	9.54				

Table 101. Adjusted means, standard errors, detectable differences, and significantly different pairs of means, based on the model analyzed in Table 102.

Source of Variation	Adjusted Mean[a]	Standard Error	Detectable Difference[b]	Significant Differences[c]						
Year					5	6	7	8		
1985	1.141	0.008	1.37	1985						
1986	1.162	0.006	1.01	1986						
1987	1.165	0.005	0.84	1987	*					
1988	1.143	0.005	0.86	1988		*	*			
1989	1.106	0.005	0.89	1989	*	*	*	*		
Month					1	2	3	4	5	6
May	1.260	0.031	4.82	May						
June	1.219	0.023	3.70	June	*					
July	1.187	0.013	2.15	July	*	*				
August	1.150	0.006	1.02	Aug	*	*	*			
September	1.098	0.016	2.86	Sept	*	*	*	*		
October	1.059	0.024	4.44	Oct	*	*	*	*	*	
November	1.030	0.027	5.15	Nov	*	*	*	*	*	*
Plantation					G	A	C			
Ground	1.134	0.004	0.69	Ground						
Antenna	1.140	0.004	0.69	Antenna						
Control	1.155	0.004	0.68	Control	*	*				

a/ mean of transformed data

b/ estimated shift in the sample mean which would be detected 95 percent of the time (α = .05), calculated as $t_{.05,n}$*S.E./Mean, and expressed as a percentage of the sample mean

c/ α = .05, least squares means pairwise comparisons

Table 102. Covariance analysis table for detection of differences in dry matter mass loss (arcsin square root of the proportion of initial mass remaining) from **Bulk Oak** leaf samples in the three **Plantation** subunits, using three covariates: 1) **ATDDRT**, running total of air temperature degree days (4.4°C basis), 2) **PR.01RT**, running total of days with precipitation events totalling at least 0.01 inch, and 3) **PR.1RT**, running total of days with precipitation events totalling at least 0.10 inch.

Source of Variation	df	SS	Type III SS	F	Signif. of F	r^2
Model	15	7.90		196.05	0.0000	0.83
Year	4		0.27	25.20	0.0001	
Month	6		0.01	0.87	0.5143	
Plantation	2		0.06	10.39	0.0001	
ATDDRT	1		0.00	1.82	0.1772	
PR.01RT	1		0.00	0.63	0.4264	
PR.1RT	1		0.02	6.82	0.0092	
Error	610	1.64				
Corrected Total	625	9.54				

Table 103. Adjusted means, standard errors, detectable differences and significantly different pairs of means, based on the model analyzed in Table 104.

Source of Variation	Adjusted Mean[a]	Standard Error	Detectable Difference[b]	Significant Differences[c]						
Year					5	6	7	8		
1985	1.154	0.008	1.36	1985						
1986	1.152	0.007	1.19	1986						
1987	1.172	0.006	1.00	1987	*					
1988	1.133	0.006	1.04	1988		*	*			
1989	1.108	0.005	0.88	1989	*	*	*	*		
Month					1	2	3	4	5	6
May	1.204	0.034	5.53	May						
June	1.178	0.025	4.16	June						
July	1.165	0.014	2.36	July						
August	1.146	0.006	1.03	Aug						
September	1.119	0.016	2.80	Sept						
October	1.100	0.026	4.63	Oct						
November	1.092	0.033	5.92	Nov						
Plantation					G	A	C			
Ground	1.132	0.004	0.69	Ground						
Antenna	1.139	0.004	0.69	Antenna						
Control	1.160	0.004	0.68	Control	*	*				

a/ mean of transformed data
b/ estimated shift in the sample mean which would be detected 95 percent of the time ($\alpha = .05$), calculated as $t_{.05,n}$*S.E./Mean, and expressed as a percentage of the sample mean
c/ $\alpha = .05$, least squares means pairwise comparisons

Table 104. Covariance analysis table (including year * plantation interaction) for detection of differences in dry matter mass loss (arcsin square root of the proportion of initial mass remaining) from **Bulk Oak** leaf samples in the three **Plantation** subunits, using three covariates: 1) **ATDDRT**, running total of air temperature degree days (4.4°C basis), 2) **PR.01RT**, running total of days with precipitation events totalling at least 0.01 inch, and 3) **PR.1RT**, running total of days with precipitation events totalling at least 0.10 inch.

Source of Variation	df	SS	Type III SS	F	Signif. of F	r^2
Model	23	7.95		130.82	0.0000	0.83
Year	4		0.28	26.05	0.0001	
Month	6		0.02	0.99	0.4278	
Plantation	2		0.05	9.59	0.0001	
Year*Plantation	8		0.05	2.29	0.0201	
ATDDRT	1		0.00	1.31	0.2529	
PR.01RT	1		0.00	0.01	0.9184	
PR.1RT	1		0.02	8.46	0.0038	
Error	602	1.59				
Corrected Total	625	9.54				

Table 105. Adjusted means, standard errors, detectable differences, and significantly different pairs of means, based on the model analyzed in Table 104.

Source of Variation	Adjusted Mean[a]	Standard Error	Detectable Difference[b]	Significant Differences[c]						
Year					5	6	7	8		
1985	1.156	0.008	1.36	1985						
1986	1.153	0.007	1.19	1986						
1987	1.170	0.006	1.01	1987						
1988	1.133	0.006	1.04	1988		*	*			
1989	1.106	0.005	0.89	1989	*	*	*	*		
Month					1	2	3	4	5	6
May	1.212	0.035	5.66	May						
June	1.184	0.026	4.30	June						
July	1.167	0.014	2.35	July						
August	1.146	0.006	1.03	Aug						
September	1.117	0.017	2.98	Sept						
October	1.096	0.026	4.65	Oct						
November	1.084	0.033	5.97	Nov						
Plantation					G	A	C			
Ground	1.132	0.004	0.69	Ground						
Antenna	1.140	0.004	0.69	Antenna						
Control	1.159	0.004	0.68	Control	*	*				

a/ mean of transformed data
b/ estimated shift in the sample mean which would be detected 95 percent of the time (α = .05), calculated as $t_{.05,n}$*S.E./Mean, and expressed as a percentage of the sample mean
c/ α = .05, least squares means pairwise comparisons

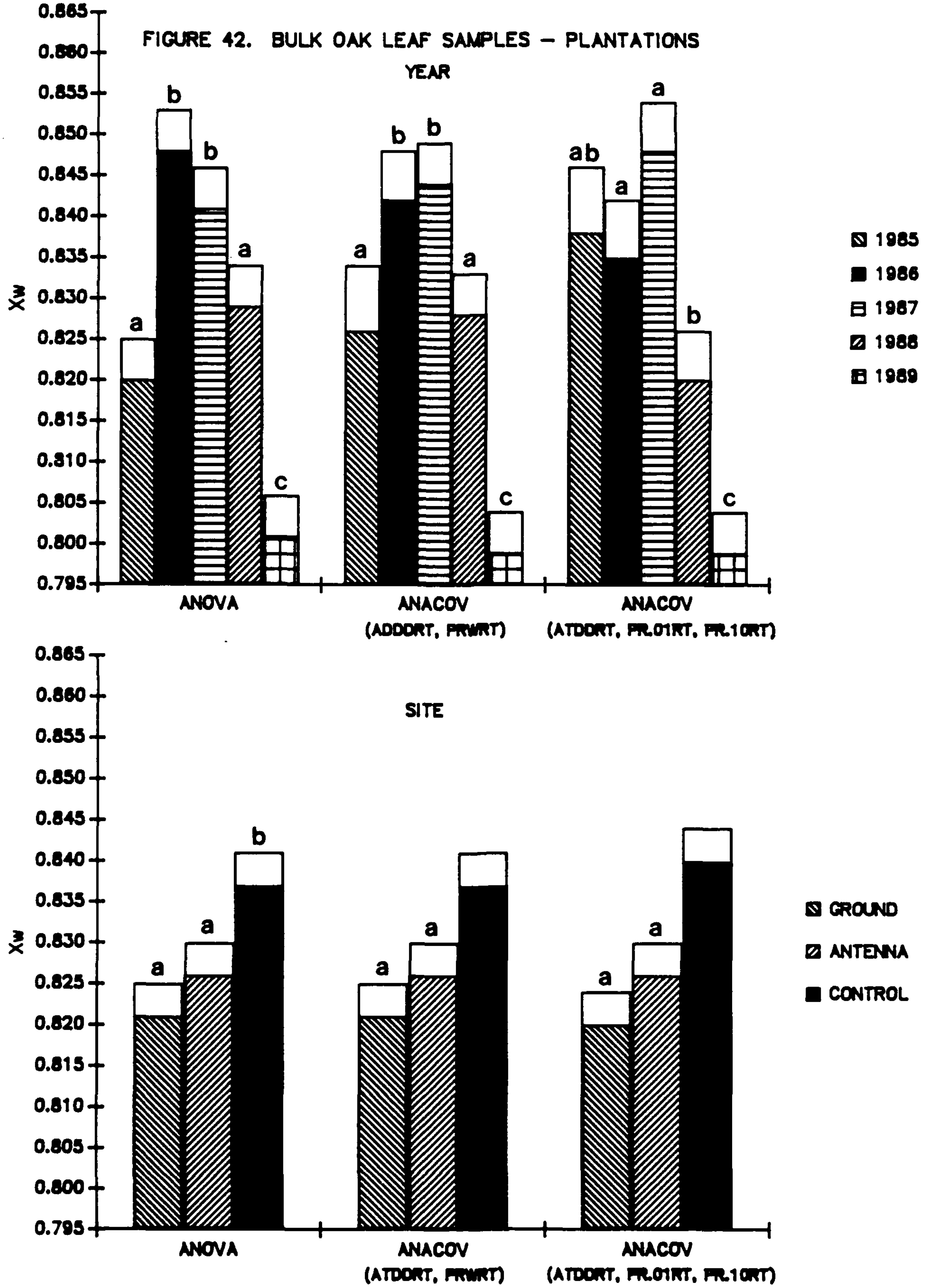


FIGURE 42. BULK OAK LEAF SAMPLES – PLANTATIONS

Table 106. Covariance analysis table for detection of differences in dry matter mass loss (arcsin square root of the proportion of initial mass remaining) from **Bulk Oak** leaf samples in the two **Hardwood Stand** subunits, using two covariates: 1) **PR.1RT**, running total of days with precipitation events totalling at least 0.10 inch, and 2) **PRWRT**, running total of precipitation.

Source of Variation	df	SS	Type III SS	F	Signif. of F	r^2
Model	14	7.37		251.05	0.0000	0.89
Year	4		0.37	44.32	0.0001	
Month	7		0.12	8.45	0.0001	
Hardwood Stand	1		0.00	2.34	0.1266	
PR.1RT	1		0.06	29.05	0.0001	
PRWRT	1		0.01	5.01	0.0257	
Error	440	0.92				
Corrected Total	454	8.29				

Table 107. Adjusted means, standard errors, detectable differences, and significantly different pairs of means, based on the model analyzed in Table 108.

Source of Variation	Adjusted Mean[a]	Standard Error	Detectable Difference[b]	Significant Differences[c]							
Year					5	6	7	8			
1985	1.168	0.008	1.34	1985							
1986	1.180	0.006	1.00	1986							
1987	1.185	0.006	0.99	1987	*						
1988	1.156	0.006	1.02	1988		*	*				
1989	1.101	0.005	0.89	1989	*	*	*	*			
Month					1	2	3	4	5	6	7
May	1.242	0.018	2.84	May							
June	1.237	0.014	2.22	June							
July	1.218	0.010	1.61	July							
August	1.191	0.007	1.15	Aug	*	*	*				
September	1.134	0.007	1.21	Sept	*	*	*	*			
October	1.092	0.011	1.97	Oct	*	*	*	*	*		
November	1.094	0.016	2.87	Nov	*	*	*	*	*		
December	1.056	0.020	3.71	Dec	*	*	*	*	*	*	*
Hardwood Stand					A	C					
Antenna	1.157	0.003	0.51	Antenna							
Control	1.159	0.003	0.51	Control							

a/ mean of transformed data
b/ estimated shift in the sample mean which would be detected 95 percent of the time (α = .05), calculated as $t_{.05,n}$*S.E./Mean, and expressed as a percentage of the sample mean
c/ α = .05, least squares means pairwise comparisons

Table 108. Covariance analysis table (including year * stand interaction) for detection of differences in dry matter mass loss (arcsin square root of the proportion of initial mass remaining) from **Bulk Oak** leaf samples in the two **Hardwood Stand** subunits, using two covariates: 1) **PR.1RT**, running total of days with precipitation events totalling at least 0.10 inch, and 2) **PRWRT**, running total of precipitation.

Source of Variation	df	SS	Type III SS	F	Signif. of F	r^2
Model	18	7.45		214.27	0.0000	0.90
Year	4		0.38	48.55	0.0001	
Month	7		0.12	8.76	0.0001	
Hardwood Stand	1		0.00	0.21	0.6448	
Year * Stand	4		0.08	10.40	0.0001	
PR.1RT	1		0.02	8.09	0.0047	
PRWRT	1		0.00	0.14	0.7120	
Error	436	0.84				
Corrected Total	454	8.29				

Table 109. Adjusted means, standard errors, detectable differences, and significantly different pairs of means, based on the model analyzed in Table 110.

Source of Variation	Adjusted Mean[a]	Standard Error	Detectable Difference[b]	Significant Differences[c]							
Year					5	6	7	8			
1985	1.167	0.008	1.34	1985							
1986	1.183	0.006	0.99	1986							
1987	1.187	0.005	0.83	1987	*						
1988	1.151	0.006	1.02	1988		*	*				
1989	1.105	0.005	0.89	1989	*	*	*	*			
Month					1	2	3	4	5	6	7
May	1.129	0.016	2.55	May							
June	1.127	0.013	2.08	June							
July	1.113	0.009	1.45	July	*	*					
August	1.189	0.007	1.15	Aug	*	*	*				
September	1.137	0.007	1.21	Sept	*	*	*	*			
October	1.199	0.011	1.96	Oct	*	*	*	*	*		
November	1.107	0.015	2.66	Nov	*	*	*	*	*		
December	1.169	0.018	3.30	Dec	*	*	*	*	*	*	*
Hardwood Stand							A		C		
Antenna	1.155	0.003	0.51	Antenna							
Control	1.163	0.004	0.67	Control							

a/ mean of transformed data
b/ estimated shift in the sample mean which would be detected 95 percent of the time (α = .05), calculated as $t_{.05,n}$*S.E./Mean, and expressed as a percentage of the sample mean
c/ α = .05, least squares means pairwise comparisons

FIGURE 43. BULK OAK LEAF SAMPLES - HARDWOOD STANDS

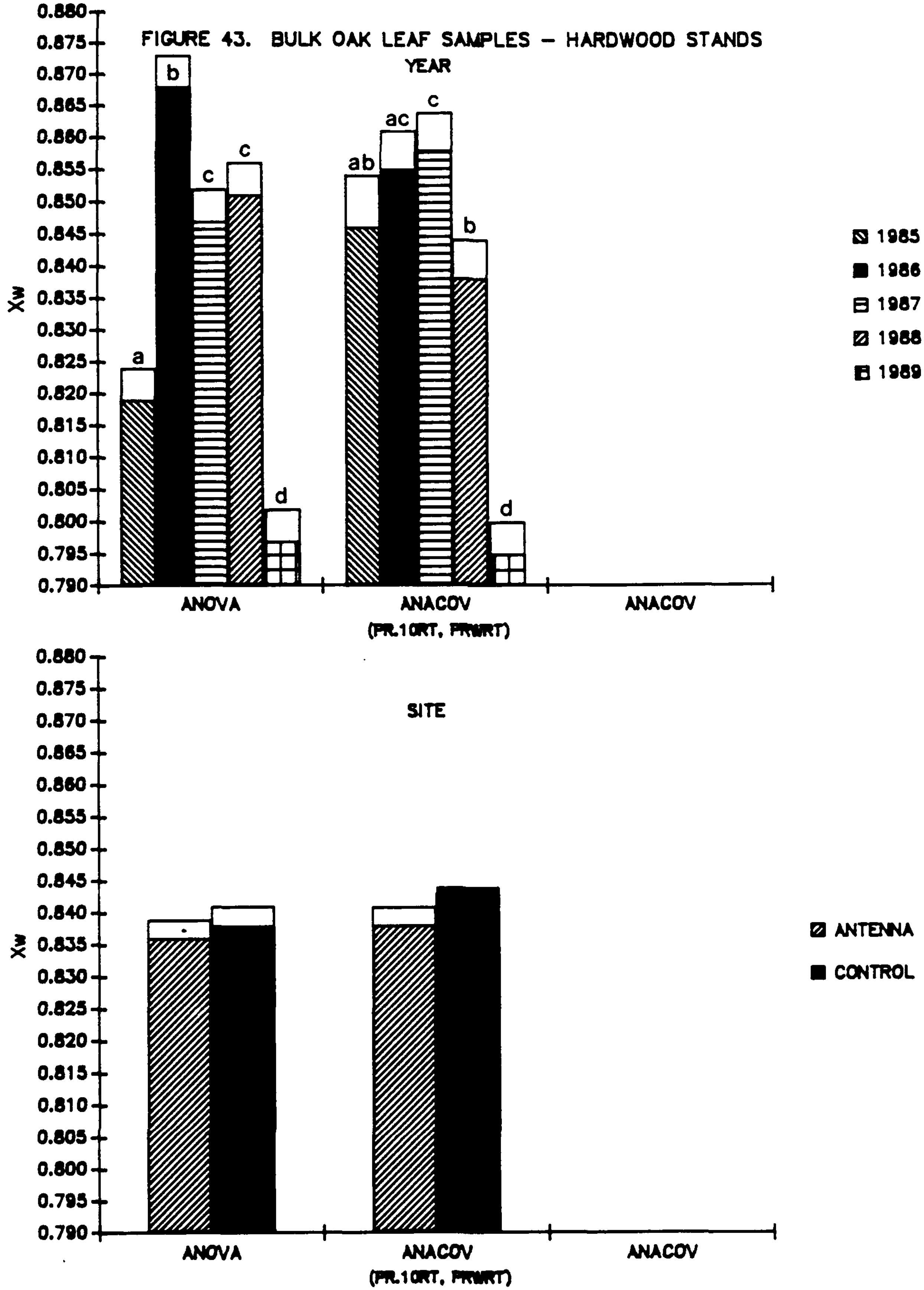


Table 110. Covariance analysis table for detection of differences in dry matter mass loss (arcsin square root of the proportion of initial mass remaining) from **Bulk Maple** leaf samples in the three **Plantation** subunits, using one covariate: **PRWRT**, running total of precipitation.

Source of Variation	df	SS	Type III SS	F	Signif. of F	r^2
Model	13	11.00		318.95	0.0000	0.87
Year	4		3.87	364.54	0.0000	
Month	6		0.88	55.38	0.0001	
Plantation	2		0.11	21.58	0.0001	
PRWRT	1		0.01	2.03	0.1545	
Error	610	1.62				
Corrected Total	623	12.62				

Table 111. Adjusted means, standard errors, detectable differences, and significantly different pairs of means, based on the model analyzed in Table 112.

Source of Variation	Adjusted Mean[a]	Standard Error	Detectable Difference[b]	Significant Differences[c]						
Year					5	6	7	8		
1985	0.822	0.007	1.67	1985						
1986	0.982	0.006	1.20	1986	*					
1987	0.983	0.005	1.00	1987	*					
1988	0.915	0.005	1.07	1988	*	*	*			
1989	1.100	0.005	0.89	1989	*	*	*	*		
Month					1	2	3	4	5	6
May	1.127	0.010	1.74	May						
June	1.062	0.008	1.48	June	*					
July	1.015	0.007	1.35	July	*	*				
August	0.960	0.006	1.23	Aug	*	*	*			
September	0.897	0.006	1.31	Sept	*	*	*	*		
October	0.841	0.009	2.10	Oct	*	*	*	*	*	
November	0.821	0.011	2.63	Nov	*	*	*	*	*	*
Plantation					G	A	C			
Ground	0.948	0.004	0.83	Ground						
Antenna	0.954	0.004	0.82	Antenna						
Control	0.980	0.004	0.80	Control	*	*				

a/ mean of transformed data

b/ estimated shift in the sample mean which would be detected 95 percent of the time (α = .05), calculated as $t_{.05,n}$*S.E./Mean, and expressed as a percentage of the sample mean

c/ α = .05, least squares means pairwise comparisons

Table 112. Covariance analysis table (including year * plantation interaction) for detection of differences in dry matter mass loss (arcsin square root of the proportion of initial mass remaining) from **Bulk Maple** leaf samples in the three **Plantation** subunits, using one covariate: **PRWRT**, running total of precipitation.

Source of Variation	df	SS	Type III SS	F	Signif. of F	r^2
Model	21	11.13		213.57	0.0000	0.88
Year	4		3.83	385.82	0.0000	
Month	6		0.82	55.13	0.0001	
Plantation	2		0.12	23.35	0.0001	
Year*Plantation	8		0.13	6.30	0.0001	
PRWRT	1		0.01	2.73	0.0992	
Error	602	1.49				
Corrected Total	623	12.62				

Table 113. Adjusted means, standard errors, detectable differences, and significantly different pairs of means, based on the model analyzed in Table 114.

Source of Variation	Adjusted Mean[a]	Standard Error	Detectable Difference[b]	Significant Differences[c]						
Year					5	6	7	8		
1985	0.821	0.007	1.67	1985						
1986	0.983	0.006	1.20	1986	*					
1987	0.983	0.005	1.00	1987	*					
1988	0.915	0.005	1.07	1988	*	*	*			
1989	1.100	0.005	0.89	1989	*	*	*	*		
Month					1	2	3	4	5	6
May	1.129	0.010	1.74	May						
June	1.064	0.008	1.47	June	*					
July	1.017	0.007	1.35	July	*	*				
August	0.961	0.005	1.02	Aug	*	*	*			
September	0.896	0.006	1.31	Sept	*	*	*	*		
October	0.839	0.009	2.10	Oct	*	*	*	*	*	
November	0.819	0.011	2.63	Nov	*	*	*	*	*	*
Plantation						G	A	C		
Ground	0.948	0.004	0.83	Ground						
Antenna	0.954	0.003	0.62	Antenna						
Control	0.981	0.004	0.80	Control		*	*			

a/ mean of transformed data

b/ estimated shift in the sample mean which would be detected 95 percent of the time (α = .05), calculated as $t_{.05,n}$*S.E./Mean, and expressed as a percentage of the sample mean

c/ α = .05, least squares means pairwise comparisons

affect treatment means, detectable differences, or the outcome of multiple comparisons. Figure 44 depicts the results of ANOVA and ANACOV for bulk maple samples in the plantations, with the year by site interaction included.

For the hardwood stands, Tables 114 - 117 present the results of ANACOV models using PR.01RT and PRWRT as covariates. Decomposition proceeded faster in the antenna stand than in the control stand. Decomposition was fastest in 1985, slowest in 1989, and faster in 1988 than in 1986 or 1987 (n.s.d.). Decomposition progressed significantly during most months. Detectable differences were well below 2 percent for years, well below 1 percent for stands, but nearly 5 percent for November. The year by stand interaction was highly significant, but had little affect on treatment means or detectable differences, and did not affect the outcome of multiple comparisons. Figure 45 depicts the results of ANOVA and ANACOV for bulk maple in the hardwood stands, with the year by stand interaction included.

ANACOV Results - Summary

The following outline summarizes the most useful results obtained to date from ANACOV on transformed dry matter mass loss data.

I. Subunits
- A. Plantations
  1. Pine
     - a. For individual fascicles, ANOVA indicates that decomposition proceeds faster in the ground and control plantations (n.s.d.) than in the antenna plantation. ANACOV with ATDDRT places the rate of decomposition at the control site between those for the ground and antenna plantations; ANACOV with both ATDDRT and PR.01RT indicates that decomposition in the antenna and control plantations (n.s.d.) proceeds faster than in the ground plantation.
     - b. For bulk samples, both ANOVA and ANACOV with PR.1RT indicate that decomposition proceeds faster in the ground and control plantations than in the antenna plantation.
  2. Oak
     - a. For individual leaves, neither ANOVA nor ANACOV found any significant differences among plantations.
     - b. For bulk samples, both ANOVA and ANACOV (using either ATDDRT and PRWRT or ATDDRT, PR.1RT, and PR.01RT) indicate that decomposition proceeded faster in the ground and antenna plantations than in the control plantation.
  3. Maple
     - a. For bulk samples, both ANOVA and ANACOV using PRWRT found that decomposition proceeded faster in the ground and antenna plantations than in the control plantation.

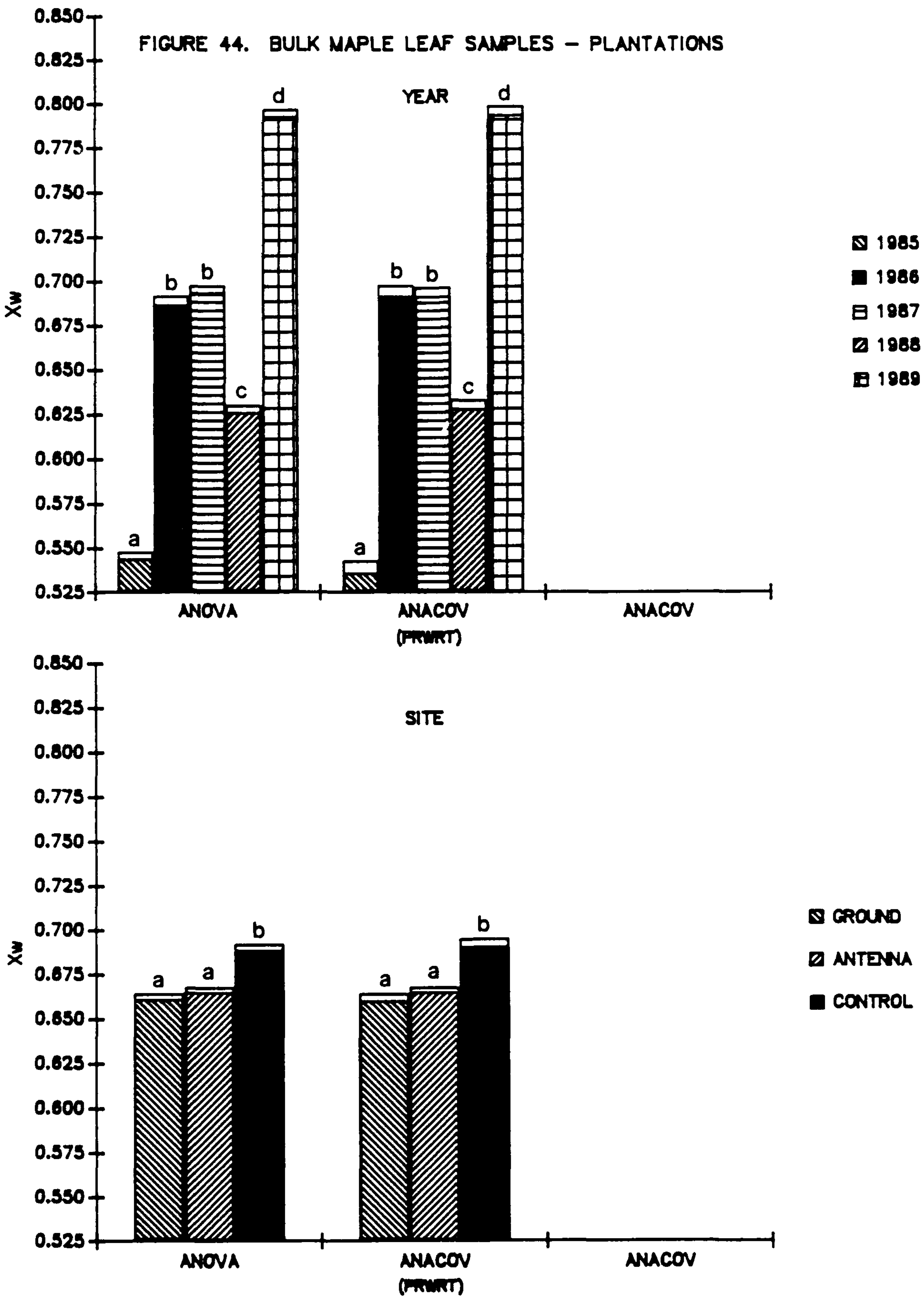


FIGURE 44. BULK MAPLE LEAF SAMPLES - PLANTATIONS
YEAR
SITE
Xw
0.850
0.825
0.800
0.775
0.750
0.725
0.700
0.675
0.650
0.625
0.600
0.575
0.550
0.525
a
b
c
d
ANOVA
ANACOV (PRWRT)
ANACOV
1985
1986
1987
1988
1989
GROUND
ANTENNA
CONTROL

Table 114. Covariance analysis table for detection of differences in dry matter mass loss (arcsin square root of the proportion of initial mass remaining) from **Bulk Maple** leaf samples in the two **Hardwood Stand** subunits, using two covariates: 1) **PR.01RT**, running total of days with precipitation events totalling at least 0.01 inch, and 2) **PRWRT**, running total of precipitation.

Source of Variation	df	SS	Type III SS	F	Signif. of F	r^2
Model	14	6.89		294.18	0.0000	0.90
Year	4		2.25	335.84	0.0000	
Month	7		0.16	13.87	0.0001	
Hardwood Stand	1		0.03	15.55	0.0001	
PR.01RT	1		0.00	1.25	0.2639	
PRWRT	1		0.00	0.03	0.8578	
Error	440	0.74				
Corrected Total	454	7.63				

Table 115. Adjusted means, standard errors, detectable differences, and significantly different pairs of means, based on the model analyzed in Table 116.

Source of Variation	Adjusted Mean[a]	Standard Error	Detectable Difference[b]	Significant Differences[c]							
Year					5	6	7	8			
1985	0.880	0.007	1.56	1985							
1986	1.064	0.006	1.11	1986	*						
1987	1.057	0.007	1.30	1987	*						
1988	0.963	0.006	1.22	1988	*	*	*				
1989	1.146	0.005	0.86	1989	*	*	*	*			
Month					1	2	3	4	5	6	7
May	1.175	0.019	3.17	May							
June	1.126	0.014	2.44	June	*						
July	1.111	0.010	1.76	July	*	*					
August	1.058	0.006	1.11	Aug	*	*	*				
September	1.994	0.006	1.18	Sept	*	*	*	*			
October	0.936	0.011	2.30	Oct	*	*	*	*	*		
November	0.908	0.018	3.89	Nov	*	*	*	*	*	*	
December	0.869	0.022	4.96	Dec	*	*	*	*	*	*	*
Hardwood Stand					A	C					
Antenna	1.013	0.003	0.58	Antenna							
Control	1.031	0.003	0.57	Control	*						

a/ mean of transformed data
b/ estimated shift in the sample mean which would be detected 95 percent of the time (α = .05), calculated as $t_{.05,n}$*S.E./Mean, and expressed as a percentage of the sample mean
c/ α = .05, least squares means pairwise comparisons associated comparative statistics for the treatments

Table 116. Covariance analysis table (including year * stand interaction) for detection of differences in dry matter mass loss (arcsin square root of the proportion of initial mass remaining) from **Bulk Maple** leaf samples in the two **Hardwood Stand** subunits, using two covariates: 1) **PR.01RT**, running total of days with precipitation events totalling at least 0.01 inch, and 2) **PRWRT**, running total of precipitation.

Source of Variation	df	SS	Type III SS	F	Signif. of F	r^2
Model	18	6.97		255.72	0.0000	0.91
Year	4		1.96	323.96	0.0000	
Month	7		0.14	13.36	0.0001	
Hardwood Stand	1		0.03	18.81	0.0001	
Year * Stand	4		0.08	12.59	0.0001	
PR.01RT	1		0.00	0.26	0.6130	
PRWRT	1		0.00	0.06	0.7990	
Error	436	0.66				
Corrected Total	454	7.63				

Table 117. Adjusted means, standard errors, detectable differences, and significantly different pairs of means, based on the model analyzed in Table 118.

Source of Variation	Adjusted Mean[a]	Standard Error	Detectable Difference[b]	Significant Differences[c]							
Year					5	6	7	8			
1985	0.884	0.007	1.55	1985							
1986	1.061	0.006	1.11	1986	*						
1987	1.060	0.007	1.29	1987	*						
1988	0.961	0.006	1.22	1988	*	*	*				
1989	1.147	0.005	0.85	1989	*	*	*	*			
Month					1	2	3	4	5	6	7
May	1.163	0.018	3.03	May							
June	1.117	0.014	2.46	June	*						
July	1.106	0.009	1.59	July	*						
August	1.055	0.006	1.11	Aug	*	*	*				
September	1.997	0.006	1.18	Sept	*	*	*	*			
October	0.942	0.011	2.29	Oct	*	*	*	*	*		
November	0.919	0.018	3.84	Nov	*	*	*	*	*	*	
December	0.883	0.021	4.66	Dec	*	*	*	*	*	*	*
Hardwood Stand					A	C					
Antenna	1.013	0.003	0.58	Antenna							
Control	1.032	0.003	0.57	Control	*						

a/ mean of transformed data
b/ estimated shift in the sample mean which would be detected 95 percent of the time (α = .05), calculated as $t_{.05,n}$*S.E./Mean, and expressed as a percentage of the sample mean
c/ α = .05, least squares means pairwise comparisons

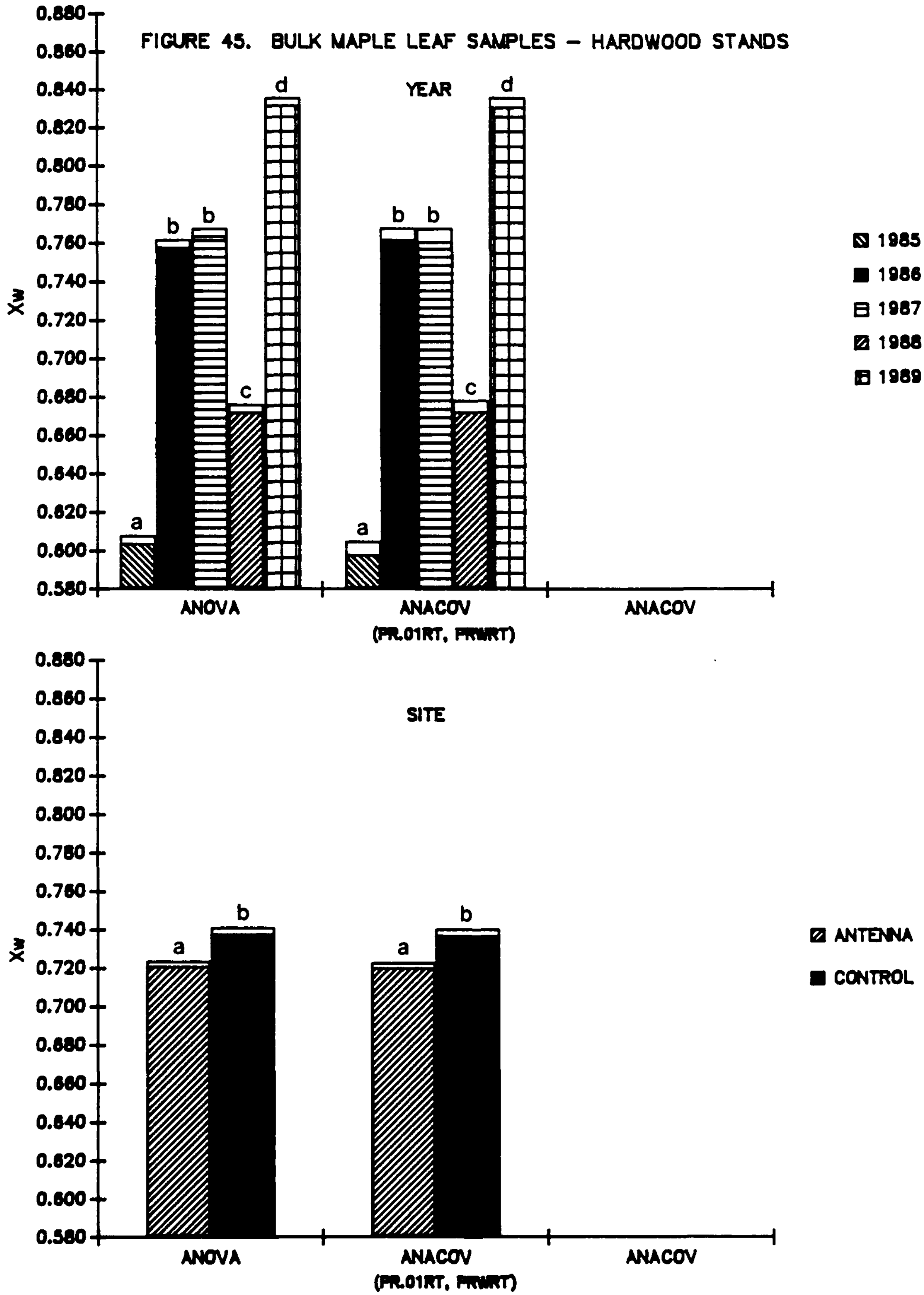


FIGURE 45. BULK MAPLE LEAF SAMPLES - HARDWOOD STANDS
YEAR
SITE
Xw
0.880
0.860
0.840
0.820
0.800
0.780
0.760
0.740
0.720
0.700
0.680
0.660
0.640
0.620
0.600
0.580
a
b
c
d
1985
1986
1987
1988
1989
ANTENNA
CONTROL
ANOVA
ANACOV
(PR.01RT, PRWRT)

B. Hardwood Stands
   1. Pine
      a. For individual fascicles, neither ANOVA nor ANACOV (either with PR.1RT alone or with both ST5DDRT and PRWRT) detected a significant difference between the hardwood stands.
      b. For bulk samples, both ANOVA and ANACOV indicate that decomposition proceeds faster in the antenna hardwood stand than in the control stand.
   2. Oak
      a. For individual leaves, both ANOVA and ANACOV (either with DENSITY and PRWRT, or with PR.01RT as a third covariate) indicate that decomposition proceeds faster in the antenna hardwood stand than in the control stand.
      b. For bulk samples, neither ANOVA nor ANACOV detected significant difference between the two stands.
   3. Maple
      a. For bulk samples, both ANOVA and ANACOV using PRWRT and PR.01RT found that decomposition proceeded faster in the antenna hardwood stand than in the control stand.

II. Years
   A. Plantations
      1. Pine
         a. For individual fascicles, both ANOVA and ANACOV with ATDDRT indicate that decomposition proceeded fastest in 1987 and 1988 (n.s.d.), but ANOVA indicates that decomposition was slowest in 1985, and ANACOV with ATDDRT indicates that decomposition was slowest both in 1985 and 1989 (n.s.d.). ANACOV with ATDDRT and PR.01RT indicates that decomposition was slowest in 1987 and 1989 (n.s.d.) and intermediate in 1986 and 1988 (n.s.d.).
         b. For bulk samples, ANOVA found no similarities in decomposition rate among years. ANACOV using PR.1RT indicates that decomposition proceeded fastest in 1985, 1986, and 1989 (n.s.d.), and that decomposition rates for 1985 and 1988 were also similar.
      2. Oak
         a. For individual leaves, ANOVA indicated that decomposition proceeded faster in 1988 and in 1989 (n.s.d.) than in either 1985 or 1986. ANACOV, using either PRWRT alone or PRWRT with ST5DDRT, indicated that decomposition proceeded faster in 1987, 1988, and 1989 (n.s.d.) than in 1985 and 1986 (n.s.d.).
         b. For bulk samples, both ANOVA and ANACOV using ATDDRT and PRWRT detected similarities between the decomposition rates for 1985 and 1988, and for 1986 and 1987. ANACOV using ATDDRT, PR.01RT, and PR.1RT indicated similarity among 1985, 1986, and 1987, as well as between 1985 and 1988.

3. Maple
   a. For bulk samples, both ANOVA and ANACOV using PRWRT indicate similarity between the rates of decomposition for 1986 and 1987.

B. Hardwood Stands
1. Pine
   a. For individual fascicles, ANOVA indicates that decomposition proceeded at a similar and intermediate rate during 1986 and 1988. ANACOV with PR.1RT indicates similar intermediate rates for 1985 and 1986, and for 1985 and 1987. ANACOV using both ST5DDRT and PRWRT indicates that decomposition was slowest during 1988 and 1989 (n.s.d.) and intermediate during 1986 and 1987 (n.s.d.).
   b. For bulk samples, ANOVA indicated similarities between the intermediate decomposition rates for 1986 and 1987, and for 1987 and 1989. ANACOV using PR.1RT indicates that decomposition rate was faster during 1985, 1986, and 1989 (n.s.d.) than during 1987 and 1988 (n.s.d.).
2. Oak
   a. For individual leaves, ANOVA found similarity between the decomposition rates for 1985 and 1987, and for 1987 and 1988. ANACOV using DENSITY and PRWRT also found similarity between 1985 and 1987, but ANACOV using PR.01RT as well indicated that decomposition proceeded faster in 1988 and 1989 (n.s.d.) than in 1985, 1986, and 1987 (n.s.d.).
   b. For bulk samples, ANOVA found similarity between the decomposition rates for 1987 and 1988. ANACOV using PRWRT and PR.1RT indicated similarities between 1985 and 1986, between 1986 and 1987, and between 1985 and 1988.
3. Maple
   a. For bulk samples, both ANOVA and ANACOV using PRWRT and PR.01RT indicate that decomposition proceede at similar rates for 1986 and 1987.

ANACOV has been very effective both for explaining some of the differences detected by ANOVA and for strengthening the explanations of other differences already provided by ANOVA. The major goals of our ANACOV analysis are to explain as many as possible of the differences in decomposition rate detected by ANOVA 1) between the two hardwood stands and between the three plantations, and 2) among years. This will be especially challenging for the plantations, because they are changing rapidly and becoming increasingly different with age.

With ANACOV, differences between the two hardwood stands have been explained for individual pine fascicles and for bulk oak leaf samples, but no difference was initially detected by ANOVA. For the remaining sample types, the faster rate of decomposition in the antenna hardwood stand than in the control stand remains unexplained.

ANACOV has not been as effective for explaining the differences among the three plantations over all years as it has for explaining the differences between some of the annual decomposition rates observed in the plantations. Differences in decomposition rate between the three plantations are explained only for individual oak leaves, for which no significant differences were found using ANOVA. For the remaining sample types, analyses failed to explain the relatively faster rate of decomposition in the ground plantation. Nevertheless, individual pine fascicles decomposed as quickly in the control plantation as in the ground plantation, and ANACOV explained the difference between the antenna and control plantations. Bulk pine samples also decomposed as quickly in the control plantation as those in the ground plantation; covariates have yet to explain the slower decomposition in the antenna plantation. Decomposition of bulk oak and maple samples proceeded as quickly in the antenna plantation as in the ground plantation; covariates have not explained the slower decomposition in the control plantation.

Individual oak leaf density failed to explain differences between plantations or hardwood stands in the five-year data set, but was useful for explaining the differences between some annual rates of decomposition. The initial nutrient content of the parent litter collections failed to explain the differences among years detected for any of the five litter sample types, either in the hardwood stands or in the plantations.

We anticipate that explanation of all differences in decomposition rate among years for all litter sample types is probably an unrealistic goal, especially in the plantation subunits, where relatively rapid successional vegetational changes add to and interact with yearly differences in weather patterns. We have been satisfied so far to identify covariates which explain differences between pre-ELF years (1985 and 1986) and ELF years (1987 and, especially, 1988 and 1989). ELF exposure was minimal in 1987. At least one similarity between a pre-ELF and an ELF year has been found for individual pine fascicles in the plantations (1986 and 1988, 1987 and 1989) and in the hardwood stands (1986 and 1987), for bulk pine needles in the plantations (1985, 1986, and 1989, and 1985 and 1988) and hardwood stands (1985, 1986, and 1989), for bulk oak leaves in the plantations (1985 and 1988, and 1985, 1986, and 1987) and hardwood stands (1986 and 1987), and for bulk maple leaves in the plantations (1986 and 1987) and hardwood stands (1986 and 1987). For individual oak leaves, decomposition has proceeded faster in 1988 and 1989 than in 1985 and 1986.

For the 1990 annual report, we will be working with initial lignin content as an additional category 1 covariate and with at least one AET-type category 5 covariate, as well as with δX as an alternative dependent variable. Estimated ELF field strengths at litterbag locations may also be considered. We expect to be able to explain additional year and site differences with these new tools. One reason for the poorer performance of weather-related covariates with the five-year data set compared to that with the four-year data set lies in the way we have utilized weather

variables to date as though they functioned independently and in linear fashion to influence decomposition rate. We expect that AET-type variables will integrate the simultaneous influences of weather-related variables to represent their combined influence on decomposition rate in a much more flexible manner.

The significance of year by site interactions will also be evaluated for the 1990 report. We anticipate that an ELF field effect would produce a significant year by site interaction, with the relationship among sites changing as ELF fields become established and/or as cumulative ELF field dosages increase. In future years, we will not present the results of ANOVA or ANACOV models without the year by site interaction term.

Nutrient Content of Bulk Standards

The random samples drawn periodically from the parent litter collections during the course of field sample preparation are referred to as bulk standards. These samples are used to estimate the initial condition of the litter comprising the field samples. The percent N, P, K, Ca, Mg, and ash contents of the bulk standards from each annual study are presented in Tables 118 - 123, along with the results of multiple comparison tests based on one-way ANOVA for detection of differences among years in percent mass of each nutrient for each species.

Significant differences among years were detected by ANOVA for all species/nutrient combinations. For this reason, the mean percent N, P, K, Ca and Mg contents of the parent litter collections representing each species in each annual decomposition study are being evaluated for use as covariates to help explain differences among years in decomposition rates.

Nutrient Content of Retrieved Samples

Nutrient flux involved with bulk sample decomposition for each litter species has been determined for each annual experiment through the 1987-88 study. Because of resource limitations, only the samples collected in May, July, September, and November of 1987 and 1988 have been chemically analyzed. Bulk samples from the 1988-89 study are being ground for chemical analysis. For statistical analysis as covariates to explain differences among years in dry matter mass loss, the N, P, K, Ca, Mg, and ash contents of retrieved litter samples are expressed as the percent content of the retrieved samples. However, it may be difficult to establish statistical independence from ELF for nutrient content variables.

The following tables and figures represent data for the percent nutrient contents of bulk samples retrieved in the annual studies. The nitrogen contents of pine, oak and maple samples retrieved in the 1987-88 study are presented in Tables 124 - 126; analogous data for phosphorus are presented in Tables 127 - 129, for potassium in Tables 130 - 132, for calcium in Tables 133 - 135, and for magnesium in Tables 136 - 138.

For this report, figures have been prepared to compare the nitrogen and phosphorus content of litter samples of each species 1) for the 1988 field season, in the three plantations and two hardwood stands, and 2) for all years in each plantation and hardwood stand. The nitrogen contents of the bulk pine samples retrieved in 1988 from the three plantations are compared in Figure 46; analogous data for the two hardwood stands are compared in Figure 47. Yearly comparisons of the nitrogen content of bulk pine samples retrieved from each plantation and hardwood stand are presented as Figures 48 - 52. Corresponding data for the phosphorus contents of bulk pine samples are depicted as Figures 53 - 59. Analogous data for the nitrogen and phosphorus contents of the bulk oak and maple samples are presented as Figures 60 - 73 and 74 - 87.

Table 118. Percent **nitrogen** content of standards sampled from the parent litter collections of red pine, red oak and red maple corresponding to samples retrieved during the 1984 - 1989 field seasons.

					Differences[a]				
Litter Species	Year	Mean Percent	Sample Size	Standard Error	1984	1985	1986	1987	1989
Pine	1984	0.496	10	0.014					
	1985	0.429	16	0.011	*				
	1986	0.309	15	0.011	*	*			
	1987	0.367	12	0.013	*	*	*		
	1988	0.316	14	0.012	*	*		*	
	1989	0.422	13	0.012	*		*	*	*
Oak	1985	0.637	15	0.026					
	1986	0.835	17	0.024		*			
	1987	0.428	12	0.029		*	*		
	1988	0.477	14	0.027		*	*		
	1989	0.665	13	0.028			*	*	*
Maple	1985	0.537	15	0.036					
	1986	1.115	16	0.035		*			
	1987	0.494	12	0.040			*		
	1988	0.495	14	0.037			*		
	1989	0.694	15	0.036		*	*	*	*

a/ $\alpha = 0.05$, SAS Proc GLM, Least Squares Means procedure

Table 119. Percent **phosphorus** content of standards sampled from the parent litter collections of red pine, red oak and red maple corresponding to samples retrieved during the 1984 - 1989 field seasons.

					Differences[a]				
Litter Species	Year	Mean Percent	Sample Size	Standard Error	1984	1985	1986	1987	1989
Pine	1984	0.054	10	0.003					
	1985	0.037	16	0.003	*				
	1986	0.048	15	0.003		*			
	1987	0.039	12	0.003	*		*		
	1988	0.051	14	0.003		*		*	
	1989	0.045	13	0.003		*			
Oak	1985	0.071	15	0.004					
	1986	0.083	17	0.004					
	1987	0.107	12	0.005		*	*		
	1988	0.072	14	0.004				*	
	1989	0.080	13	0.005				*	
Maple	1985	0.080	15	0.005					
	1986	0.124	16	0.005		*			
	1987	0.051	12	0.006		*	*		
	1988	0.056	14	0.005		*	*		
	1989	0.063	14	0.005		*	*		

a/ $\alpha = 0.05$, SAS Proc GLM, Least Squares Means procedure

Table 120. Percent **potassium** content of standards sampled from the parent litter collections of red pine, red oak and red maple corresponding to samples retrieved during the 1984 - 1989 field seasons.

Litter Species	Year	Mean Percent	Sample Size	Standard Error	Differences[a] 1984	1985	1986	1987	1989
Pine	1984	0.413	10	0.014					
	1985	0.083	15	0.012	*				
	1986	0.059	15	0.012	*	*			
	1987	0.045	12	0.013	*	*			
	1988	0.034	14	0.012	*				
	1989	0.088	13	0.013	*			*	*
Oak	1985	0.119	15	0.006					
	1986	0.144	17	0.005		*			
	1987	0.259	12	0.006		*	*		
	1988	0.198	14	0.006		*	*	*	
	1989	0.127	13	0.006			*	*	*
Maple	1985	0.449	15	0.010					
	1986	0.212	16	0.010		*			
	1987	0.146	12	0.012		*	*		
	1988	0.372	14	0.011		*	*	*	
	1989	0.090	15	0.010		*	*	*	*

a/ $\alpha = 0.05$, SAS Proc GLM, Least Squares Means procedure

Table 121. Percent **calcium** content of standards sampled from the parent litter collections of red pine, red oak and red maple corresponding to samples retrieved during the 1984 - 1989 field seasons.

Litter Species	Year	Mean Percent	Sample Size	Standard Error	Differences[a] 1984	1985	1986	1987	1989
Pine	1984	0.592	10	0.033					
	1985	0.412	15	0.027	*				
	1986	0.350	15	0.027	*				
	1987	0.373	12	0.030	*				
	1988	0.484	14	0.028	*		*	*	
	1989	0.486	13	0.029	*		*	*	
Oak	1985	1.036	15	0.016					
	1986	0.984	17	0.015		*			
	1987	1.014	12	0.018					
	1988	0.954	14	0.016		*		*	
	1989	1.050	13	0.017			*		*
Maple	1985	0.925	15	0.025					
	1986	1.041	16	0.024		*			
	1987	0.905	12	0.028			*		
	1988	0.964	14	0.026			*		
	1989	1.073	15	0.025		*		*	*

a/ $\alpha = 0.05$, SAS Proc GLM, Least Squares Means procedure

Table 122. Percent **magnesium** content of standards sampled from the parent litter collections of red pine, red oak and red maple corresponding to samples retrieved during the 1984 - 1989 field seasons.

Litter Species	Year	Mean Percent	Sample Size	Standard Error	Differences[a] 1984	1985	1986	1987	1989
Pine	1984	0.111	10	0.003					
	1985	0.081	15	0.002	*				
	1986	0.083	15	0.002	*				
	1987	0.076	12	0.003	*				
	1988	0.082	14	0.002	*				
	1989	0.087	13	0.002					
Oak	1985	0.126	15	0.002					
	1986	0.117	17	0.002		*			
	1987	0.161	12	0.002		*	*		
	1988	0.120	14	0.002				*	
	1989	0.131	13	0.002			*	*	*
Maple	1985	0.137	15	0.004					
	1986	0.130	16	0.004					
	1987	0.114	12	0.004		*	*		
	1988	0.135	14	0.004				*	
	1989	0.100	15	0.004		*	*	*	*

a/ $\alpha = 0.05$, SAS Proc GLM, Least Squares Means procedure

Table 123. Percent **ash** weight of standards sampled from the parent litter collections of red pine, red oak and red maple corresponding to samples retrieved during the 1984 - 1989 field seasons.

Litter Species	Year	Mean Percent	Sample Size	Standard Error	Differences[a] 1984	1985	1986	1987	1989
Pine	1984	4.7	10	0.3					
	1985	3.2	15	0.3	*				
	1986	3.5	15	0.3					
	1987	3.8	12	0.3					
	1988	3.2	14	0.3	*				
Oak	1985	9.2	15	0.3					
	1986	7.9	17	0.3		*			
	1987	9.1	12	0.4					
	1988	8.4	14	0.3					
Maple	1985	10.7	15	0.4					
	1986	11.1	16	0.4					
	1987	9.6	12	0.4			*		
	1988	10.5	14	0.4					

a/ $\alpha = 0.05$, SAS Proc GLM, Least Squares Means procedure

Table 124. Mean percent total nitrogen mass (o.d.w., w/w) at different times in 1988, for bulk red pine foliar litter samples disbursed in early December, 1987.

Sampling Date	Antenna Unit					
	Plantation			Hardwood Stand		
	Mean	S.D.[a]	%[b]	Mean	S.D.	%
4 May 1 June	0.47	0.02	5	0.48	0.00	1
29 June 28 July	0.78	0.05	7	0.71	0.10	15
31 August 28 September	0.58	0.04	7	0.52	0.02	3
2 November 1 December	0.67	0.02	3	0.58	0.05	10

Table 124. (cont)

Sampling Date	Control Unit					
	Plantation			Hardwood Stand		
	Mean	S.D.	%	Mean	S.D.	%
4 May 1 June	0.49	0.03	7	0.47	0.02	6
29 June 28 July	0.68	0.10	16	0.82	0.03	4
31 August 28 September	0.58	0.03	5	0.53	0.03	5
2 November 1 December	1.03	0.66	67	0.54	0.04	7

Table 124. (cont)

Sampling Date	Ground Unit		
	Plantation		
	Mean	S.D.	%
4 May 1 June	0.47	0.03	7
29 June 28 July	0.58	0.04	8
31 August 28 September	0.59	0.01	2
2 November 1 December	0.73	0.10	14

a/ standard deviation

b/ detectable difference: the estimated shift in each mean value which would be detected 95 percent of the time (α = .05), calculated as $t_{.05,n}$ * S.E./Mean, and expressed as a percentage of the sample mean (n = 6)

Table 125. Mean percent total nitrogen mass (o.d.w., w/w) at different times in 1988, for bulk red oak foliar litter samples disbursed in early December, 1987.

Sampling Date	Antenna Unit					
	Plantation			Hardwood Stand		
	Mean	S.D.[a]	%[b]	Mean	S.D.	%
4 May 1 June	0.93	0.08	10	0.80	0.05	6
29 June 28 July	1.06	0.05	5	1.09	0.13	13
31 August 28 September	1.28	0.19	16	1.22	0.27	23
2 November 1 December	1.21	0.13	13	1.27	0.11	10

Table 125. (cont)

Sampling Date	Control Unit					
	Plantation			Hardwood Stand		
	Mean	S.D.	%	Mean	S.D.	%
4 May 1 June	0.75	0.03	5	0.79	0.01	1
29 June 28 July	1.03	0.14	14	0.98	0.02	3
31 August 28 September	1.02	0.04	4	0.98	0.04	5
2 October 1 December	1.12	0.01	1	1.20	0.11	10

Table 125. (cont)

Sampling Date	Ground Unit		
	Plantation		
	Mean	S.D.	%
4 May 1 June	0.87	0.07	9
29 June 28 July	1.13	0.19	17
31 August 28 September	1.48	0.19	13
2 November 1 December	1.19	0.11	10

a/ standard deviation

b/ detectable difference: the estimated shift in each mean value which would be detected 95 percent of the time (α = .05), calculated as $t_{.05,n}$ * S.E./Mean, and expressed as a percentage of the sample mean (n = 6)

Table 126. Mean percent total nitrogen mass (o.d.w., w/w) at different times in 1988, for bulk red maple foliar litter samples disbursed in early December, 1987.

Sampling Date	Antenna Unit					
	Plantation			Hardwood Stand		
	Mean	S.D.[a]	%[b]	Mean	S.D.	%
4 May	0.97	0.03	3	0.97	0.09	14
1 June						
29 June	1.30	0.02	2	1.19	0.08	7
28 July						
31 August	1.14	0.10	9	1.18	0.01	1
28 September						
2 November	1.27	0.09	8	1.32	0.07	5
1 December						

Table 126. (cont)

Sampling Date	Control Unit					
	Plantation			Hardwood Stand		
	Mean	S.D.	%	Mean	S.D.	%
4 May	1.04	0.07	7	1.03	0.05	5
1 June						
29 June	1.32	0.08	7	1.22	0.15	13
28 July						
31 August	1.61	0.21	16	1.51	0.01	1
28 September						
2 November	1.51	0.30	21	1.17	0.05	5
1 December						

Table 126. (cont)

Sampling Date	Ground Unit		
	Plantation		
	Mean	S.D.	%
4 May	0.98	0.03	3
1 June			
29 June	1.13	0.05	5
28 July			
31 August	1.32	0.22	17
28 September			
2 November	1.36	0.06	5
1 December			

a/ standard deviation
b/ detectable difference: the estimated shift in each mean value which would be detected 95 percent of the time (α = .05), calculated as $t_{.05,n}$ * S.E./Mean, and expressed as a percentage of the sample mean (n = 6)

Table 127. Mean percent total phosphorus mass (o.d.w., w/w) at different times in 1988, for bulk red pine foliar litter samples disbursed in early December, 1987.

Sampling Date	Antenna Unit					
	Plantation			Hardwood Stand		
	Mean	S.D.[a]	%[b]	Mean	S.D.	%
4 May 1 June	0.048	0.013	28	0.063	0.019	32
29 June 28 July	0.042	0.003	7	0.211	0.029	14
31 August 28 September	0.076	0.050	105	0.066	0.010	16
2 November 1 December	0.050	0.001	2	0.053	0.004	9

Table 127. (cont)

Sampling Date	Control Unit					
	Plantation			Hardwood Stand		
	Mean	S.D.	%	Mean	S.D.	%
4 May 1 June	0.068	0.015	24	0.104	0.044	44
29 June 28 July	0.213	0.177	87	0.092	0.015	17
31 August 28 September	0.056	0.014	26	0.068	0.018	28
2 November 1 December	0.053	0.014	27	0.053	0.003	6

Table 127. (cont)

Sampling Date	Ground Unit		
	Plantation		
	Mean	S.D.	%
4 May 1 June	0.090	0.071	83
29 June 28 July	0.050	0.006	12
31 August 28 September	0.063	0.004	7
2 November 1 December	0.079	0.029	38

a/ standard deviation
b/ detectable difference: the estimated shift in each mean value which would be detected 95 percent of the time (α = .05), calculated as $t_{.05,n}$ * S.E./Mean, and expressed as a percentage of the sample mean (n = 6)

Table 128. Mean percent total phosphorus mass (o.d.w., w/w) at different times in 1988, for bulk red oak foliar litter samples disbursed in early December, 1987.

Sampling Date	Antenna Unit					
	Plantation			Hardwood Stand		
	Mean	S.D.[a]	%[b]	Mean	S.D.	%
4 May 1 June	0.070	0.003	5	0.057	0.008	14
29 June 28 July	0.068	0.009	14	0.094	0.024	26
31 August 28 September	0.167	0.113	71	0.067	0.012	19
2 November 1 December	0.082	0.014	21	0.182	0.092	81

Table 128. (cont)

Sampling Date	Control Unit					
	Plantation			Hardwood Stand		
	Mean	S.D.	%	Mean	S.D.	%
4 May 1 June	0.088	0.021	25	0.081	0.041	54
29 June 28 July	0.058	0.008	15	0.050	0.003	9
31 August 28 September	0.092	0.032	37	0.099	0.018	19
2 November 1 December	0.063	0.007	12	0.088	0.004	4

Table 128. (cont)

Sampling Date	Ground Unit		
	Plantation		
	Mean	S.D.	%
4 May 1 June	0.099	0.034	36
29 June 28 July	0.064	0.007	11
31 August 28 September	0.085	0.011	14
2 November 1 December	0.075	0.012	17

a/ standard deviation
b/ detectable difference: the estimated shift in each mean value which would be detected 95 percent of the time (α = .05), calculated as $t_{.05,n}$ * S.E./Mean, and expressed as a percentage of the sample mean (n = 6)

Table 129. Mean percent total phosphorus mass (o.d.w., w/w) at different times in 1988, for bulk red maple foliar litter samples disbursed in early December, 1987.

Sampling Date	Antenna Unit					
	Plantation			Hardwood Stand		
	Mean	S.D.[a]	%[b]	Mean	S.D.	%
4 May 1 June	0.087	0.004	5	0.136	0.005	6
29 June 28 July	0.074	0.024	35	0.163	0.105	67
31 August 28 September	0.054	0.003	5	0.146	0.023	17
2 November 1 December	0.081	0.010	13	0.102	0.006	6

Table 129. (cont)

Sampling Date	Control Unit					
	Plantation			Hardwood Stand		
	Mean	S.D.	%	Mean	S.D.	%
4 May 1 June	0.087	0.013	16	0.093	0.009	10
29 June 28 July	0.076	0.005	7	0.090	0.023	26
31 August 28 September	0.081	0.003	4	0.098	0.013	14
2 November 1 December	0.091	0.023	26	0.096	0.010	11

Table 129. (cont)

Sampling Date	Ground Unit		
	Plantation		
	Mean	S.D.	%
4 May 1 June	0.083	0.013	17
29 June 28 July	0.114	0.043	40
31 August 28 September	0.095	0.020	22
2 November 1 December	0.084	0.004	4

a/ standard deviation
b/ detectable difference: the estimated shift in each mean value which would be detected 95 percent of the time (! = .05), calculated as $t_{.05,n}$ * S.E./Mean, and expressed as a percentage of the sample mean (n = 6)

Table 130. Mean percent total potassium mass (o.d.w., w/w) at different times in 1988, for bulk red pine foliar litter samples disbursed in early December, 1987.

Sampling Date	Antenna Unit					
	Plantation			Hardwood Stand		
	Mean	S.D.[a]	%[b]	Mean	S.D.	%
4 May 1 June	0.087	0.007	8	0.080	0.006	7
29 June 28 July	0.047	0.009	19	0.064	0.009	14
31 August 28 September	0.034	0.004	11	0.042	0.009	22
2 November 1 December	0.052	0.009	18	0.070	0.004	6

Table 130. (cont)

Sampling Date	Control Unit					
	Plantation			Hardwood Stand		
	Mean	S.D.	%	Mean	S.D.	%
4 May 1 June	0.083	0.006	7	0.092	0.010	11
29 June 28 July	0.040	0.003	8	0.072	0.000	0
31 August 28 September	0.041	0.002	4	0.048	0.001	3
2 November 1 December	0.045	0.008	19	0.062	0.007	13

Table 130. (cont)

Sampling Date	Ground Unit		
	Plantation		
	Mean	S.D.	%
4 May 1 June	0.085	0.011	14
29 June 28 July	0.035	0.018	53
31 August 28 September	0.033	0.006	20
2 November 1 December	0.040	0.004	9

a/ standard deviation
b/ detectable difference: the estimated shift in each mean value which would be detected 95 percent of the time (! = .05), calculated as $t_{.05,n}$ * S.E./Mean, and expressed as a percentage of the sample mean (n = 6)

Table 131. Mean percent total potassium mass (o.d.w., w/w) at different times in 1988, for bulk red oak foliar litter samples disbursed in early December, 1987.

	Antenna Unit					
	Plantation			Hardwood Stand		
Sampling Date	Mean	S.D.[a]	%[b]	Mean	S.D.	%
4 May 1 June	0.143	0.019	14	0.153	0.033	23
29 June 28 July	0.102	0.017	17	0.130	0.014	12
31 August 28 September	0.082	0.004	5	0.109	0.005	5
2 November 1 December	0.099	0.010	13	0.145	0.013	10

Table 131. (cont)

	Control Unit					
	Plantation			Hardwood Stand		
Sampling Date	Mean	S.D.	%	Mean	S.D.	%
4 May 1 June	0.163	0.011	7	0.134	0.018	14
29 June 28 July	0.082	0.004	5	0.092	0.008	14
31 August 28 September	0.081	0.019	25	0.099	0.009	10
2 November 1 December	0.098	0.011	11	0.142	0.006	5

Table 131. (cont)

	Ground Unit		
	Plantation		
Sampling Date	Mean	S.D.	%
4 May 1 June	0.135	0.030	23
29 June 28 July	0.101	0.006	6
31 August 28 September	0.083	0.005	6
2 November 1 December	0.096	0.007	8

a/ standard deviation
b/ detectable difference: the estimated shift in each mean value which would be detected 95 percent of the time (! = .05), calculated as $t_{.05,n}$ * S.E./Mean, and expressed as a percentage of the sample mean (n = 6)

Table 132. Mean percent total potassium mass (o.d.w., w/w) at different times in 1988, for bulk red maple foliar litter samples disbursed in early December, 1987.

Sampling Date	Antenna Unit					
	Plantation			Hardwood Stand		
	Mean	S.D.[a]	%[b]	Mean	S.D.	%
4 May 1 June	0.208	0.101	51	0.138	0.018	14
29 June 28 July	0.078	0.012	16	0.111	0.007	7
31 August 28 September	0.061	0.008	13	0.088	0.009	10
2 November 1 December	0.095	0.021	23	0.108	0.021	20

Table 132. (cont)

Sampling Date	Control Unit					
	Plantation			Hardwood Stand		
	Mean	S.D.	%	Mean	S.D.	%
4 May 1 June	0.136	0.024	19	0.129	0.006	5
29 June 28 July	0.079	0.003	4	0.095	0.003	3
31 August 28 September	0.074	0.009	16	0.084	0.001	3
2 November 1 December	0.089	0.010	12	0.114	0.001	2

Table 132. (cont)

Sampling Date	Ground Unit		
	Plantation		
	Mean	S.D.	%
4 May 1 June	0.154	0.016	11
29 June 28 July	0.081	0.012	15
31 August 28 September	0.064	0.007	12
2 November 1 December	0.079	0.007	9

a/ standard deviation

b/ detectable difference: the estimated shift in each mean value which would be detected 95 percent of the time (! = .05), calculated as $t_{.05,n}$ * S.E./Mean, and expressed as a percentage of the sample mean (n = 6)

Table 133. Mean percent total calcium mass (o.d.w., w/w) at different times in 1988, for bulk red pine foliar litter samples disbursed in early December, 1987.

Sampling Date	Antenna Unit					
	Plantation			Hardwood Stand		
	Mean	S.D.[a]	%[b]	Mean	S.D.	%
4 May 1 June	0.52	0.02	3	0.54	0.04	7
29 June 28 July	0.51	0.00	1	0.53	0.02	3
31 August 28 September	0.51	0.01	2	0.54	0.02	4
2 November 1 December	0.50	0.02	3	0.55	0.02	4

Table 133. (cont)

Sampling Date	Control Unit					
	Plantation			Hardwood Stand		
	Mean	S.D.	%	Mean	S.D.	%
4 May 1 June	0.56	0.04	8	0.53	0.02	5
29 June 28 July	0.54	0.02	4	0.50	0.02	4
31 August 28 September	0.52	0.03	6	0.52	0.03	6
2 November 1 December	0.52	0.01	2	0.59	0.05	8

Table 133. (cont)

Sampling Date	Ground Unit		
	Plantation		
	Mean	S.D.	%
4 May 1 June	0.53	0.01	3
29 June 28 July	0.51	0.01	1
31 August 28 September	0.49	0.01	3
2 November 1 December	0.54	0.00	1

a/ standard deviation
b/ detectable difference: the estimated shift in each mean value which would be detected 95 percent of the time (! = .05), calculated as $t_{.05,n}$ * S.E./Mean, and expressed as a percentage of the sample mean (n = 6)

Table 134. Mean percent total calcium mass (o.d.w., w/w) at different times in 1988, for bulk red oak foliar litter samples disbursed in early December, 1987.

Sampling Date	Antenna Unit					
	Plantation			Hardwood Stand		
	Mean	S.D.[a]	%[b]	Mean	S.D.	%
4 May	1.22	0.02	1	1.17	0.02	2
1 June						
29 June	1.10	0.03	3	1.19	0.05	5
28 July						
31 August	1.15	0.03	3	1.20	0.03	3
28 September						
2 November	1.25	0.04	4	1.27	0.03	2
1 December						

Table 134. (cont)

Sampling Date	Control Unit					
	Plantation			Hardwood Stand		
	Mean	S.D.	%	Mean	S.D.	%
4 May	1.17	0.03	3	1.19	0.02	2
1 June						
29 June	1.18	0.04	3	1.14	0.01	1
28 July						
31 August	1.06	0.03	2	1.12	0.01	1
28 September						
2 November	1.11	0.05	5	1.25	0.07	6
1 December						

Table 134. (cont)

Sampling Date	Ground Unit		
	Plantation		
	Mean	S.D.	%
4 May	1.15	0.02	1
1 June			
29 June	1.11	0.01	1
28 July			
31 August	1.11	0.05	4
28 September			
2 November	1.18	0.06	5
1 December			

a/ standard deviation
b/ detectable difference: the estimated shift in each mean value which would be detected 95 percent of the time (! = .05), calculated as $t_{.05,n}$ * S.E./Mean, and expressed as a percentage of the sample mean (n = 6)

Table 135. Mean percent total calcium mass (o.d.w., w/w) at different times in 1988, for bulk red maple foliar litter samples disbursed in early December, 1987.

Sampling Date	Antenna Unit					
	Plantation			Hardwood Stand		
	Mean	S.D.[a]	%[b]	Mean	S.D.	%
4 May 1 June	1.39	0.04	3	1.40	0.03	2
29 June 28 July	1.26	0.03	2	1.27	0.08	7
31 August 28 September	1.08	0.08	7	1.16	0.01	0
2 November 1 December	1.12	0.02	1	1.16	0.09	8

Table 135. (cont)

Sampling Date	Control Unit					
	Plantation			Hardwood Stand		
	Mean	S.D.	%	Mean	S.D.	%
4 May 1 June	1.27	0.06	5	1.19	0.04	3
29 June 28 July	1.14	0.08	7	1.18	0.13	11
31 August 28 September	1.23	0.17	18	0.98	0.41	44
2 November 1 December	1.03	0.07	7	1.10	0.07	7

Table 135. (cont)

Sampling Date	Ground Unit		
	Plantation		
	Mean	S.D.	%
4 May 1 June	1.39	0.04	3
29 June 28 July	1.25	0.04	3
31 August 28 September	1.08	0.01	1
2 November 1 December	1.09	0.06	5

a/ standard deviation
b/ detectable difference: the estimated shift in each mean value which would be detected 95 percent of the time (! = .05), calculated as $t_{.05,n}$ * S.E./Mean, and expressed as a percentage of the sample mean (n = 6)

Table 136. Mean percent total magnesium mass (o.d.w., w/w) at different times in 1988, for bulk red pine foliar litter samples disbursed in early December, 1987.

Sampling Date	Antenna Unit					
	Plantation			Hardwood Stand		
	Mean	S.D.[a]	%[b]	Mean	S.D.	%
4 May 1 June	0.094	0.005	5	0.091	0.002	3
29 June 28 July	0.080	0.003	4	0.085	0.002	3
31 August 28 September	0.064	0.005	8	0.059	0.002	4
2 November 1 December	0.057	0.008	14	0.059	0.004	8

Table 136. (cont)

Sampling Date	Control Unit					
	Plantation			Hardwood Stand		
	Mean	S.D.	%	Mean	S.D.	%
4 May 1 June	0.091	0.001	2	0.090	0.002	2
29 June 28 July	0.081	0.001	2	0.085	0.003	3
31 August 28 September	0.058	0.001	2	0.068	0.001	1
2 November 1 December	0.049	0.003	8	0.058	0.001	3

Table 136. (cont)

Sampling Date	Ground Unit		
	Plantation		
	Mean	S.D.	%
4 May 1 June	0.095	0.002	2
29 June 28 July	0.082	0.002	2
31 August 28 September	0.054	0.002	5
2 November 1 December	0.053	0.003	7

a/ standard deviation
b/ detectable difference: the estimated shift in each mean value which would be detected 95 percent of the time (α = .05), calculated as $t_{.05,n}$ * S.E./Mean, and expressed as a percentage of the sample mean (n = 6)

Table 137. Mean percent total magnesium mass (o.d.w. w/w) at different times in 1988, for bulk red oak foliar litter samples disbursed in early December, 1987.

Sampling Date	Antenna Unit					
	Plantation			Hardwood Stand		
	Mean	S.D.	%	Mean	S.D.	%
4 May 1 June	0.135	0.004	3	0.128	0.003	2
29 June 28 July	0.106	0.004	4	0.119	0.001	1
31 August 28 September	0.087	0.005	6	0.097	0.008	8
2 November 1 December	0.081	0.006	9	0.104	0.007	7

Table 137. (cont)

Sampling Date	Control Unit					
	Plantation			Hardwood Stand		
	Mean	S.D.	%	Mean	S.D.	%
4 May 1 June	0.129	0.002	1	0.134	0.003	2
29 June 28 July	0.106	0.002	2	0.119	0.005	6
31 August 28 September	0.087	0.004	4	0.107	0.007	7
2 November 1 December	0.082	0.009	11	0.110	0.006	5

Table 137. (cont)

Sampling Date	Ground Unit		
	Plantation		
	Mean	S.D.	%
4 May 1 June	0.125	0.001	1
29 June 28 July	0.109	0.002	2
31 August 28 September	0.089	0.004	5
2 November 1 December	0.088	0.009	10

a/ standard deviation
b/ detectable difference: the estimated shift in each mean value which would be detected 95 percent of the time (α = .05), calculated as $t_{.05,n}$ * S.E./Mean, and expressed as a percentage of the sample mean (n = 6)

Table 138. Mean percent total magnesium mass (o.d.w., w/w) at different times in 1988, for bulk red maple foliar litter samples disbursed in early December, 1987.

Sampling Date	Antenna Unit					
	Plantation			Hardwood Stand		
	Mean	S.D.	%	Mean	S.D.	%
4 May 1 June	0.145	0.007	5	0.144	0.005	4
29 June 28 July	0.102	0.002	2	0.122	0.006	5
31 August 28 September	0.061	0.008	14	0.097	0.004	5
2 November 1 December	0.080	0.028	36	0.120	0.005	4

Table 138. (cont)

Sampling Date	Control Unit					
	Plantation			Hardwood Stand		
	Mean	S.D.	%	Mean	S.D.	%
4 May 1 June	0.130	0.011	9	0.126	0.011	9
29 June 28 July	0.090	0.013	16	0.109	0.014	13
31 August 28 September	0.069	0.007	12	0.103	0.011	11
2 November 1 December	0.069	0.004	7	0.108	0.007	7

Table 138. (cont)

Sampling Date	Ground Unit		
	Plantation		
	Mean	S.D.	%
4 May 1 June	0.151	0.005	4
29 June 28 July	0.102	0.002	2
31 August 28 September	0.068	0.008	12
2 November 1 December	0.069	0.009	13

a/ standard deviation
b/ detectable difference: the estimated shift in each mean value which would be detected 95 percent of the time (! = .05), calculated as $t_{.05,n}$ * S.E./Mean, and expressed as a percentage of the sample mean (n = 6)

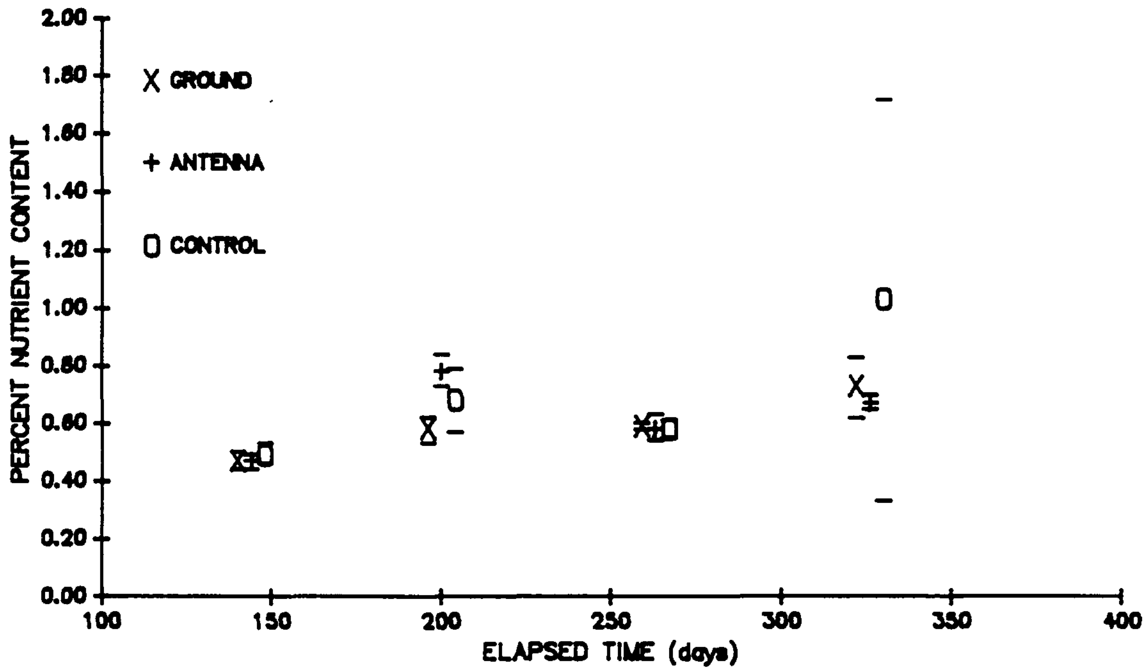


FIGURE 46. Percent nitrogen content of bulk pine needle samples retrieved from the three plantation subunits during the 1987–1988 experiment.

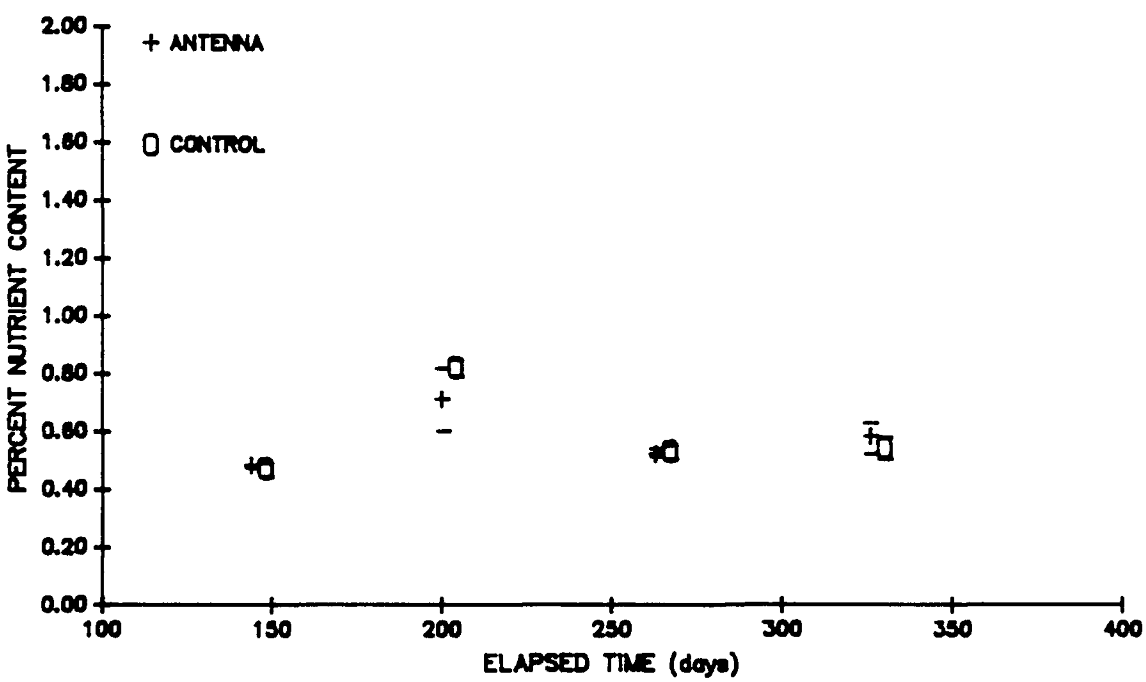


FIGURE 47. Percent nitrogen content of bulk pine needle samples retrieved from the two hardwood stand subunits during the 1987–1988 experiment.

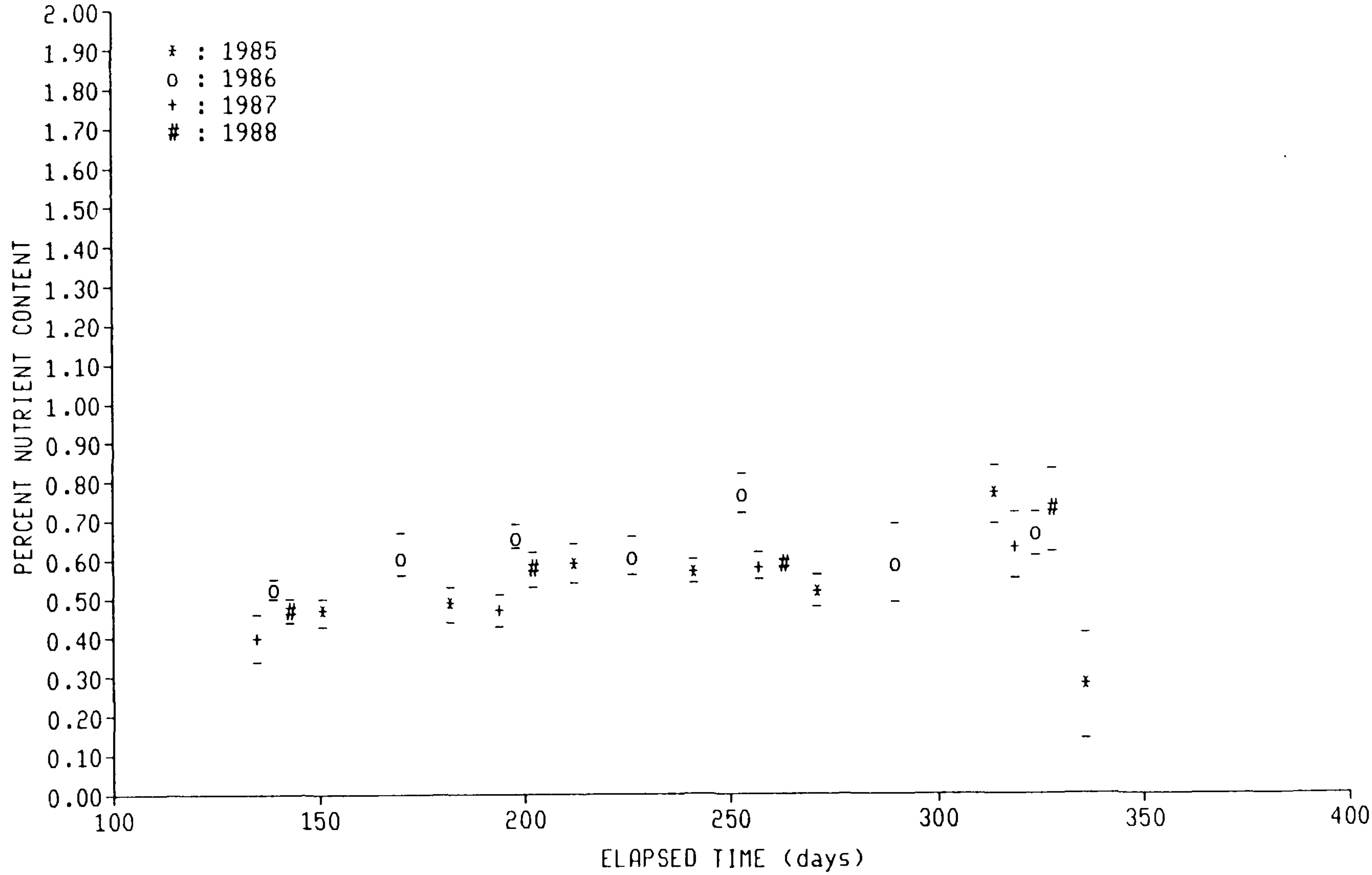


Figure 48. Percent nitrogen content of bulk pine needle samples retrieved from the ground unit plantation during the four consecutive annual experiments analyzed to date.

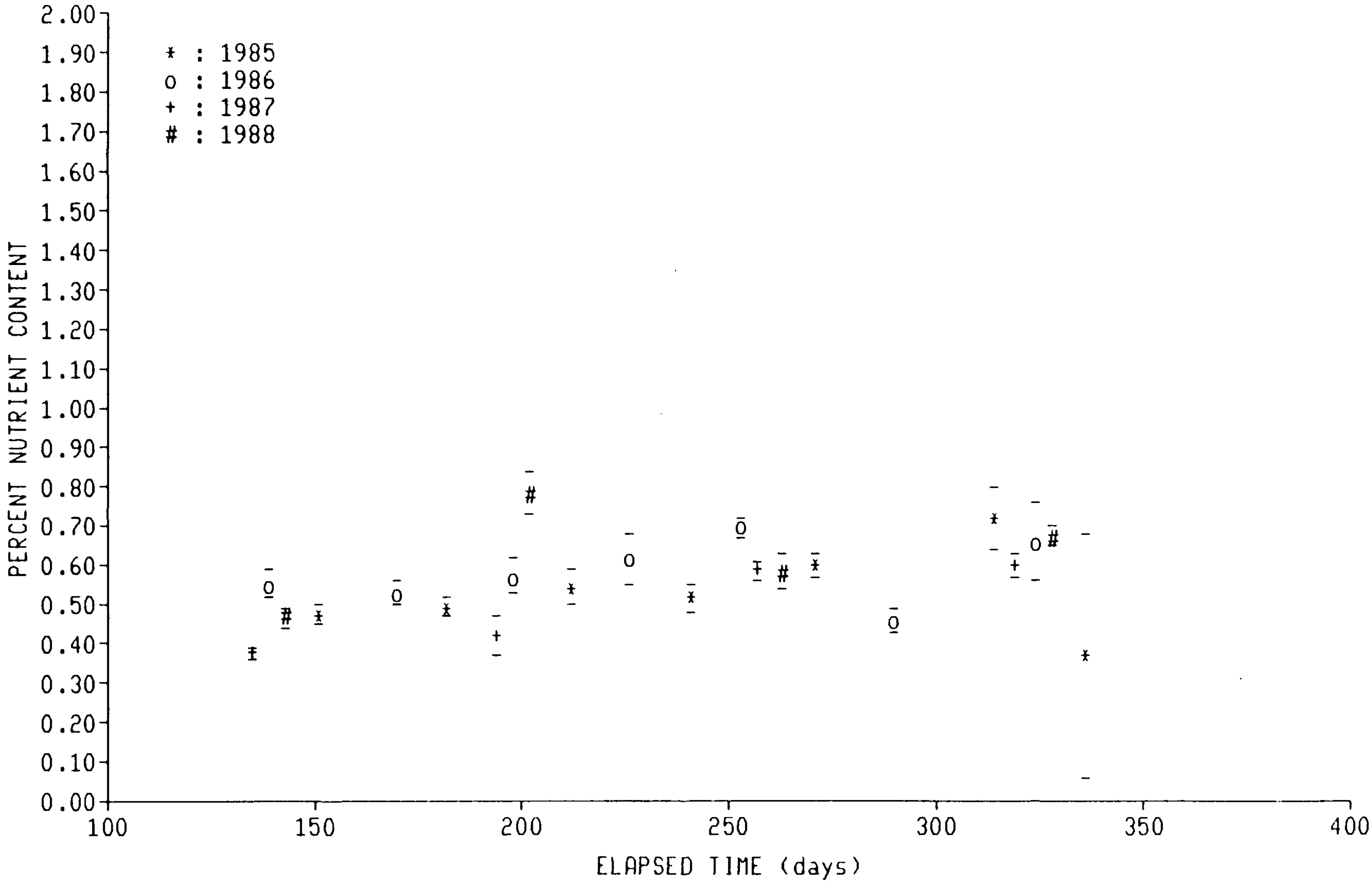


Figure 49. Percent nitrogen content of bulk pine needle samples retrieved from the antenna unit plantation during the four consecutive annual experiments analyzed to date.

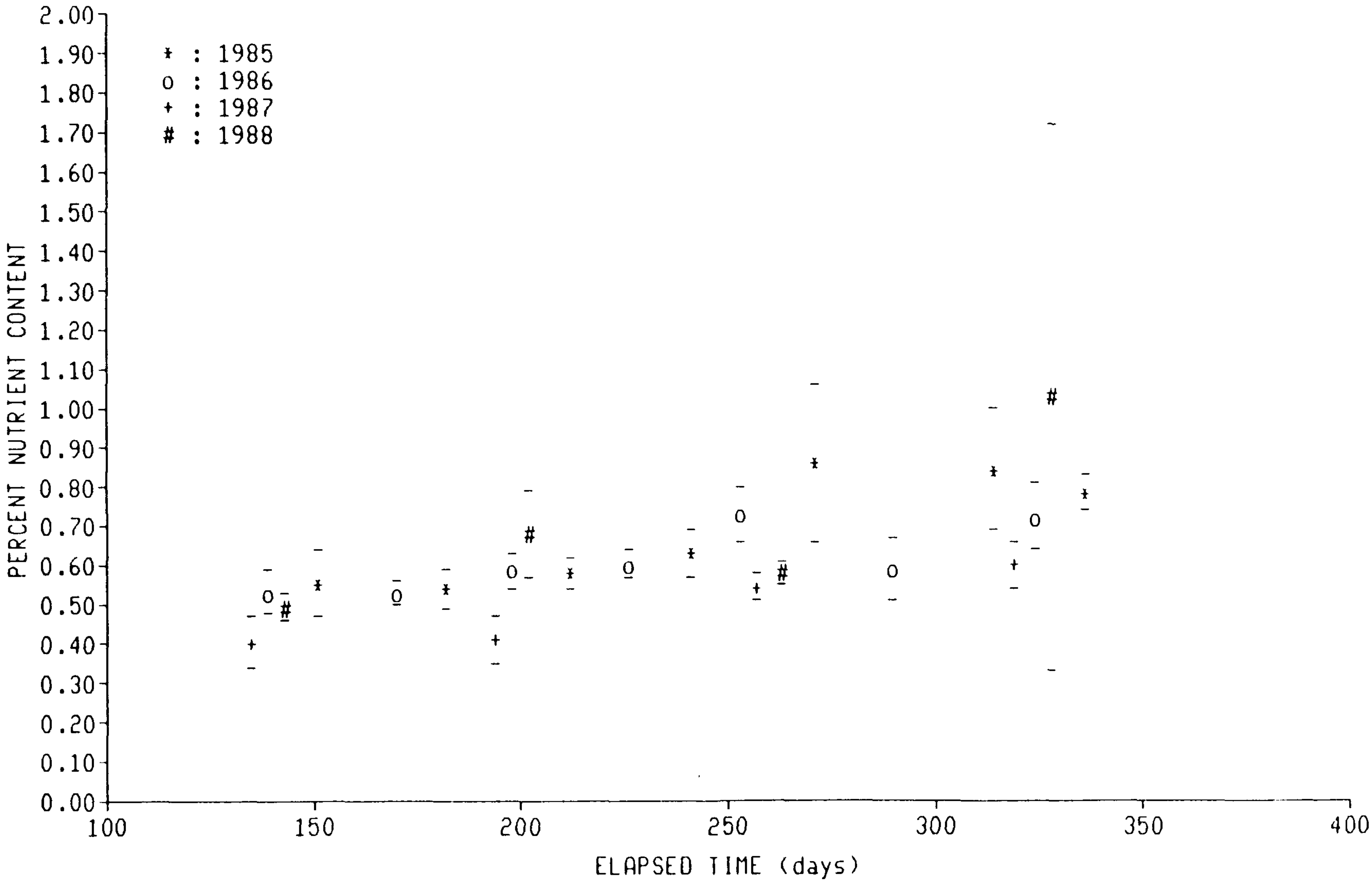


Figure 50. Percent nitrogen content of bulk pine needle samples retrieved from the control unit plantation during the four consecutive annual experiments analyzed to date.

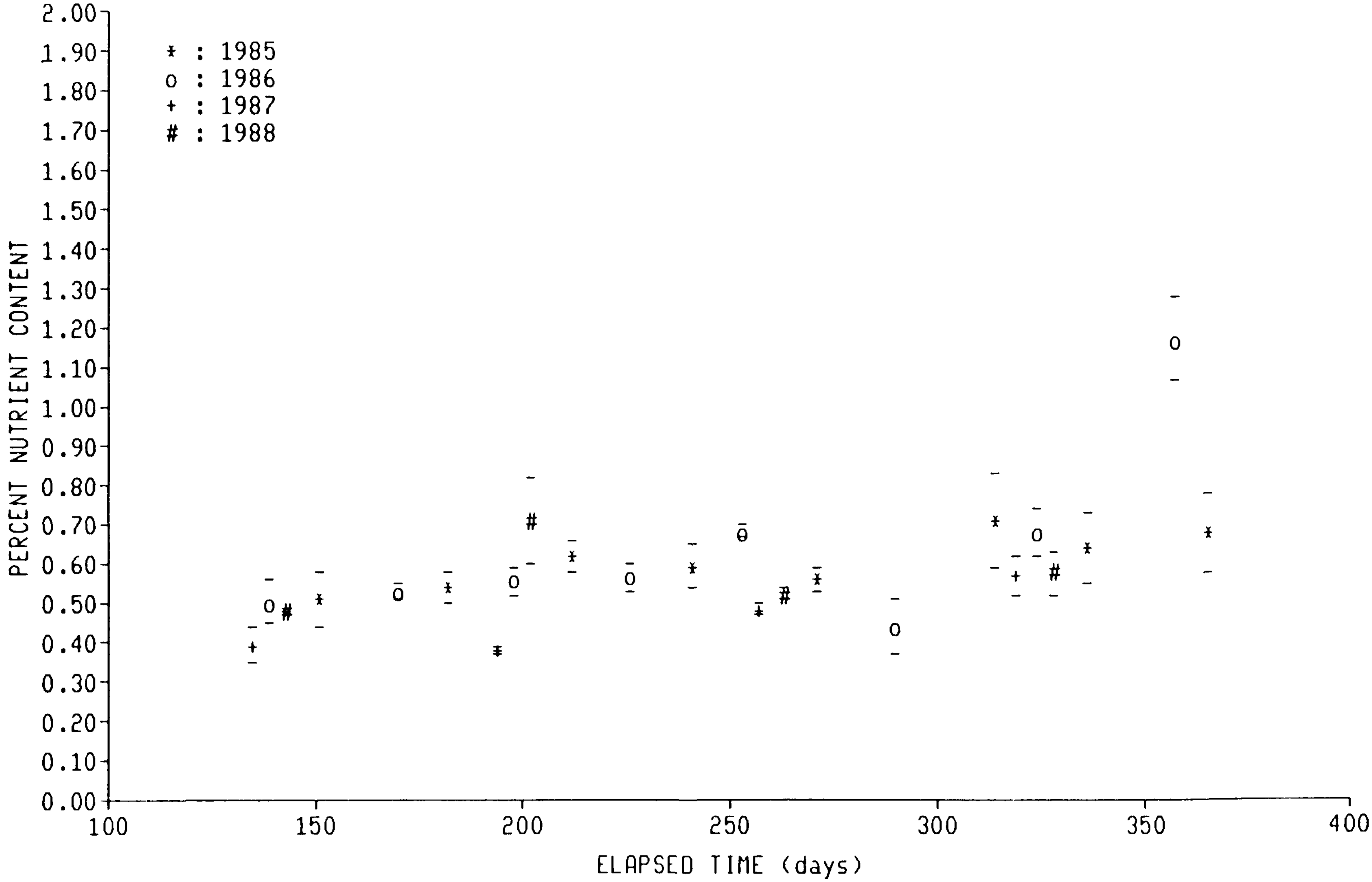


Figure 51. Percent nitrogen content of bulk pine needle samples retrieved from the antenna unit hardwood stand during the four consecutive annual experiments analyzed to date.

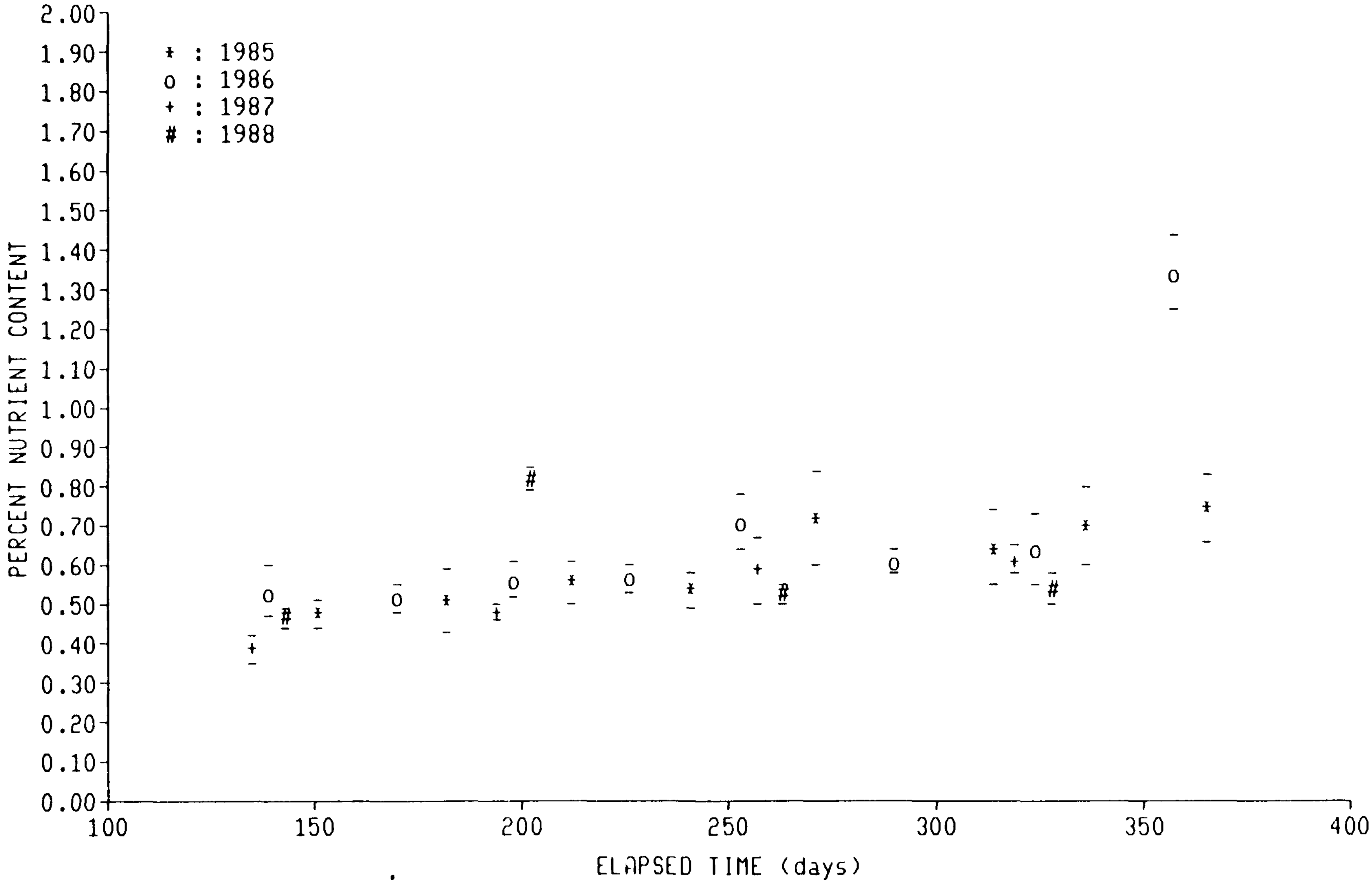


Figure 52. Percent nitrogen content of bulk pine needle samples retrieved from the control unit hardwood stand during the four consecutive annual experiments analyzed to date.

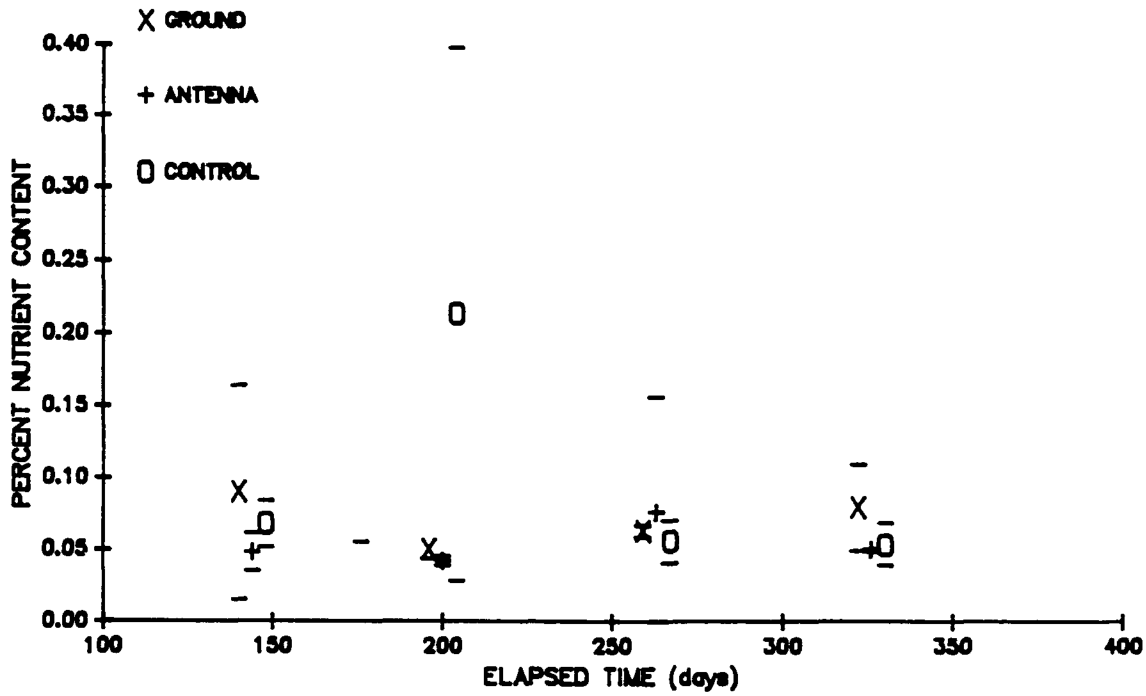


FIGURE 53. Percent phosphorus content of bulk pine needle samples retrieved from the three plantation subunits during the 1987–1988 experiment.

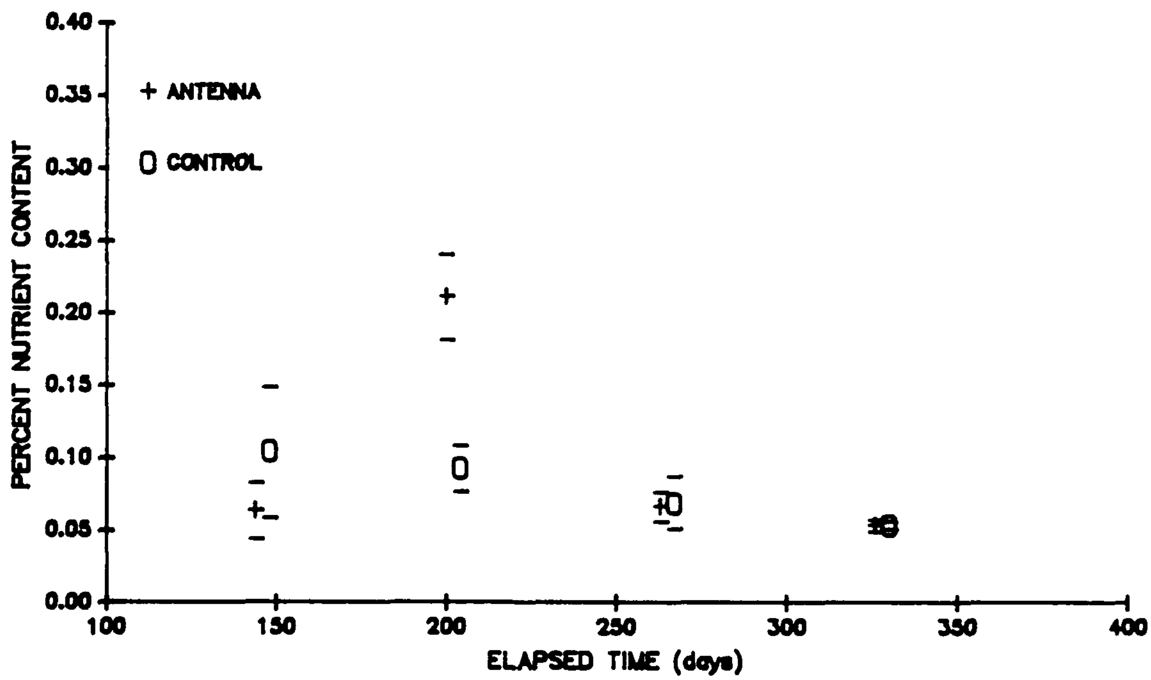


FIGURE 54. Percent phosphorus content of bulk pine needle samples retrieved from the two hardwood stand subunits during the 1987–1988 experiment.

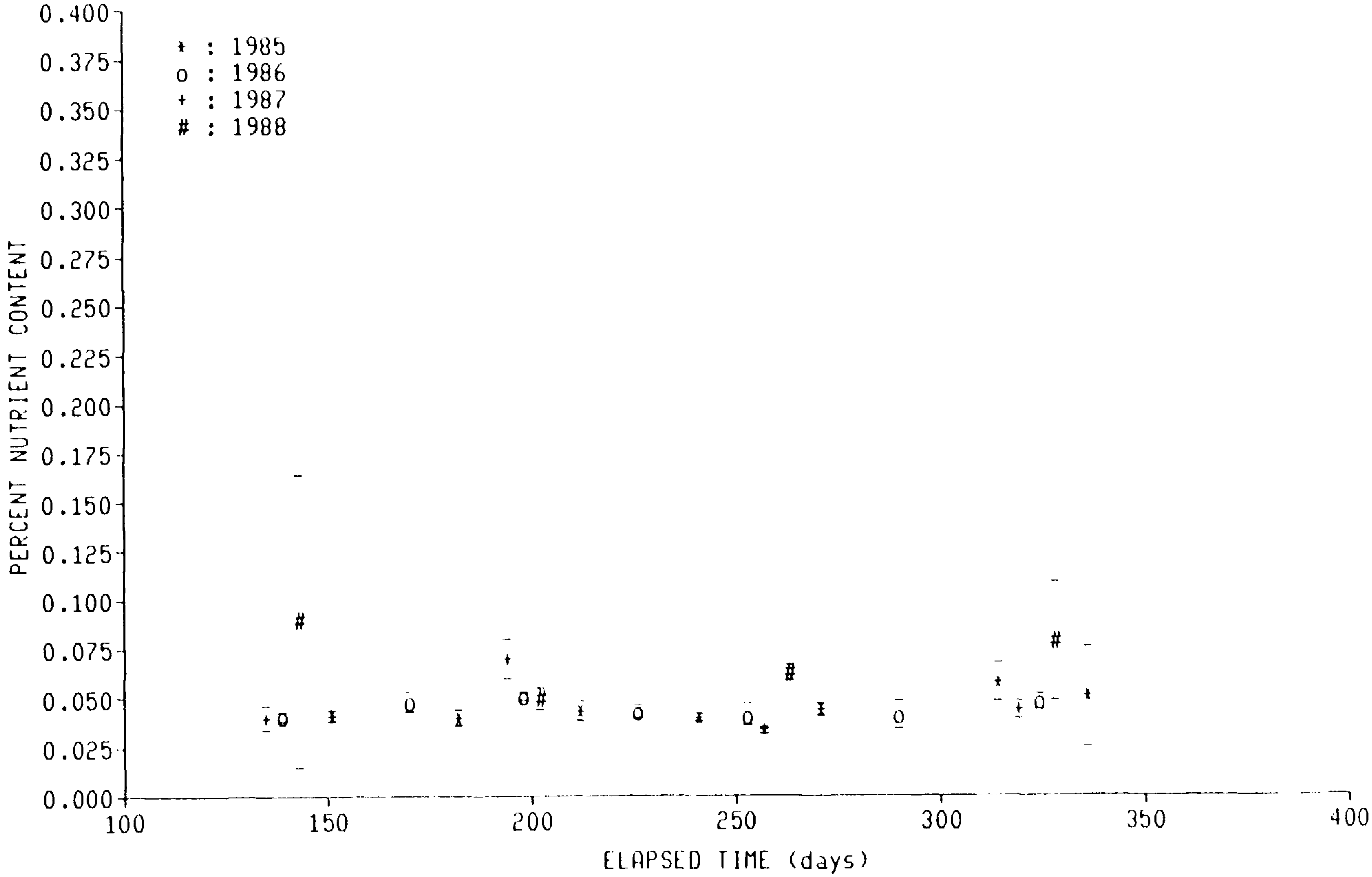


Figure 55. Percent phosphorus content of bulk pine needle samples retrieved from the ground unit plantation during the four consecutive annual experiments analyzed to date.

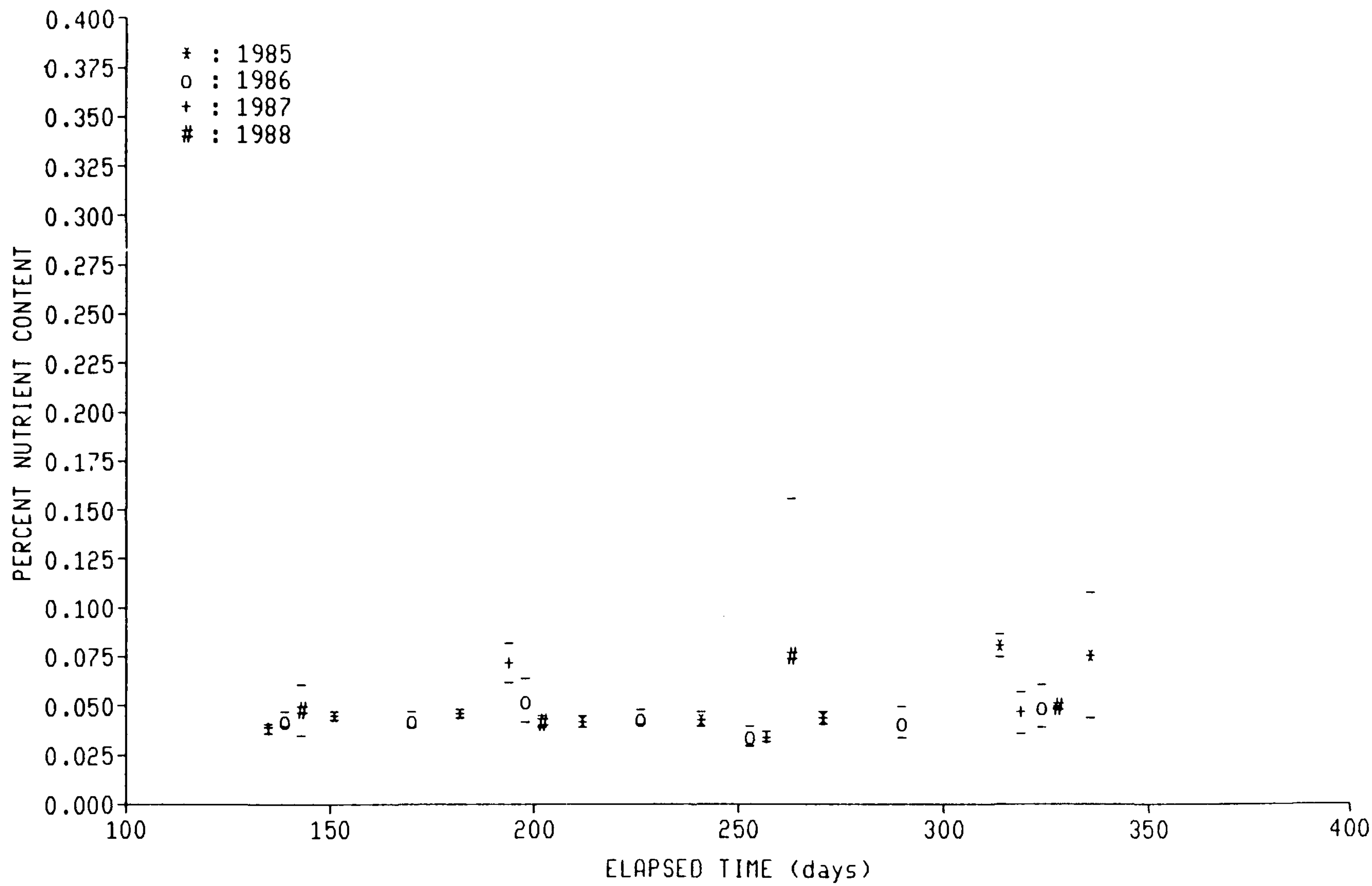


Figure 56. Percent phosphorus content of bulk pine needle samples retrieved from the antenna unit plantation during the four consecutive annual experiments analyzed to date.

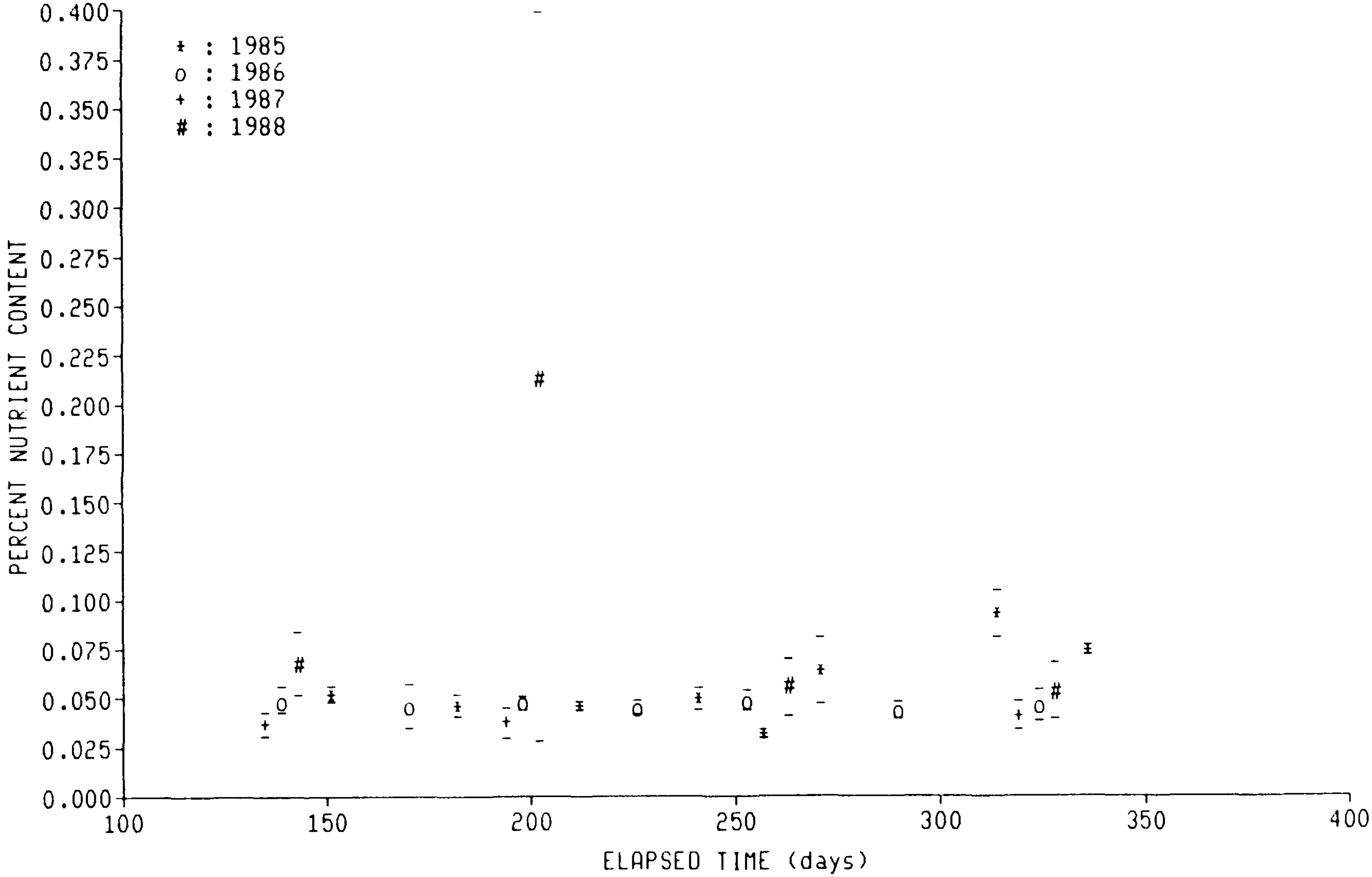


Figure 57. Percent phosphorus content of bulk pine needle samples retrieved from the control unit plantation during the four consecutive annual experiments analyzed to date.

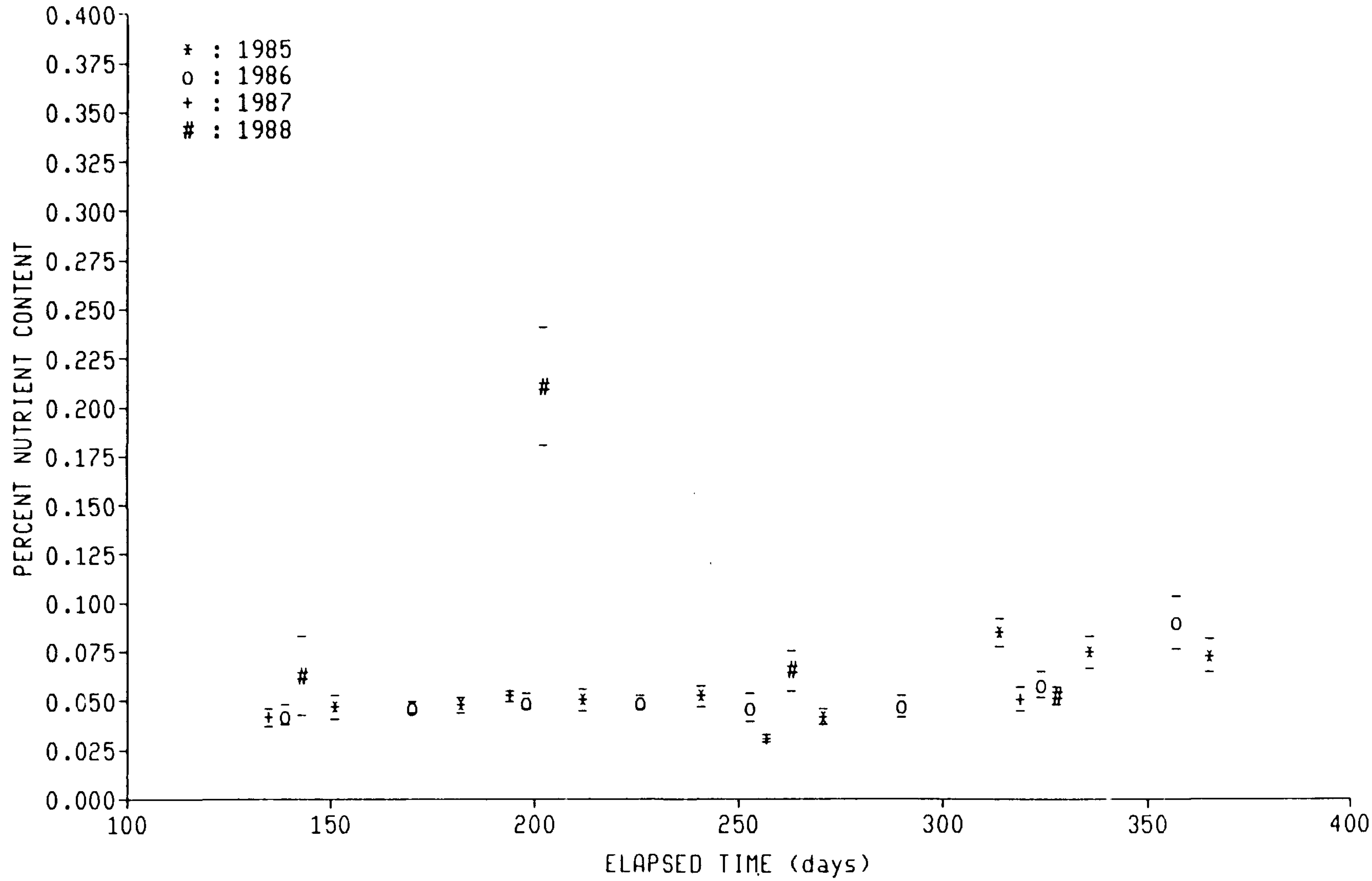


Figure 58. Percent phosphorus content of bulk pine needle samples retrieved from the antenna unit hardwood stand during the four consecutive annual experiments analyzed to date.

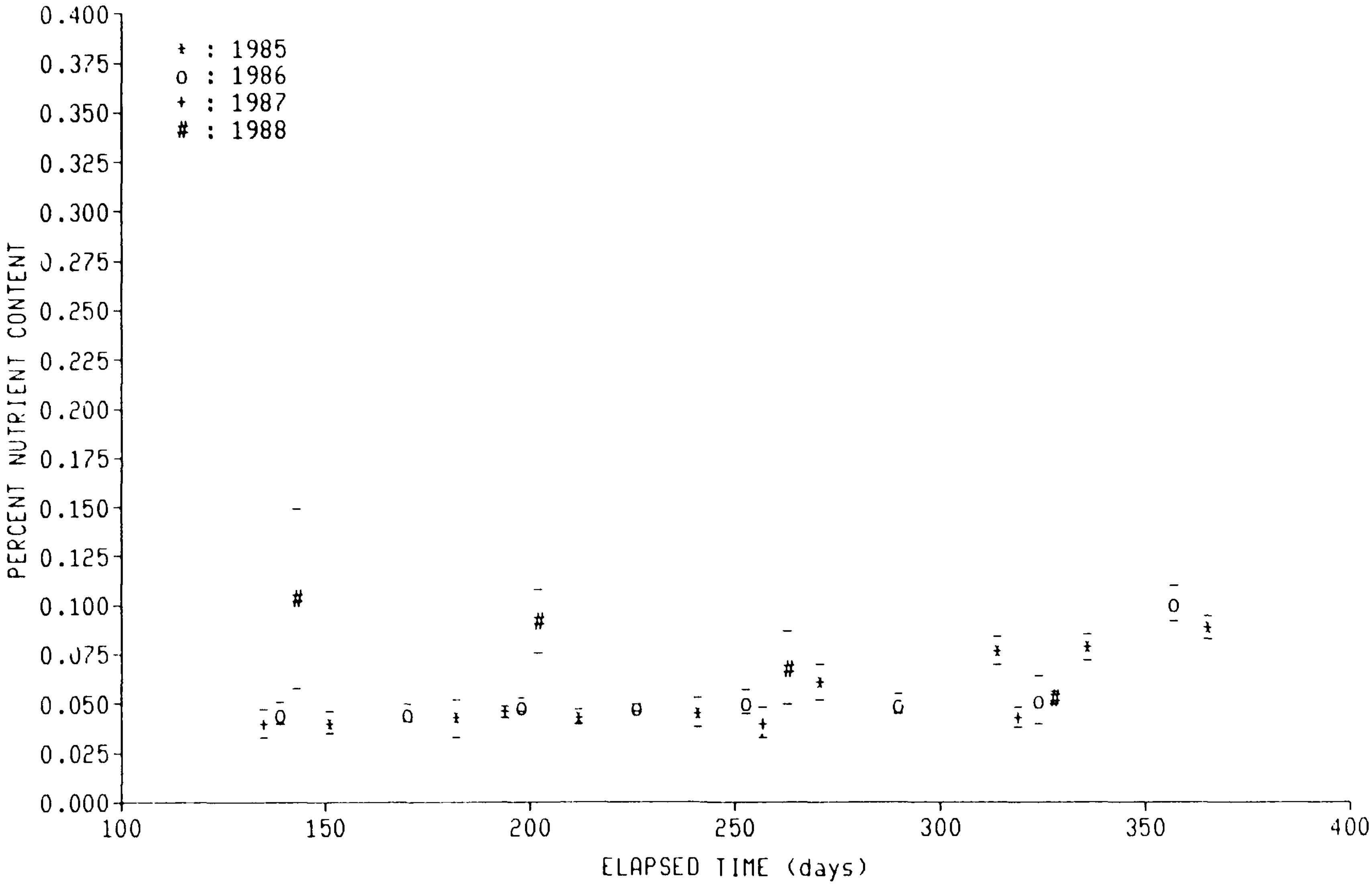


Figure 59. Percent phosphorus content of bulk pine needle samples retrieved from the control unit hardwood stand during the four consecutive annual experiments analyzed to date.

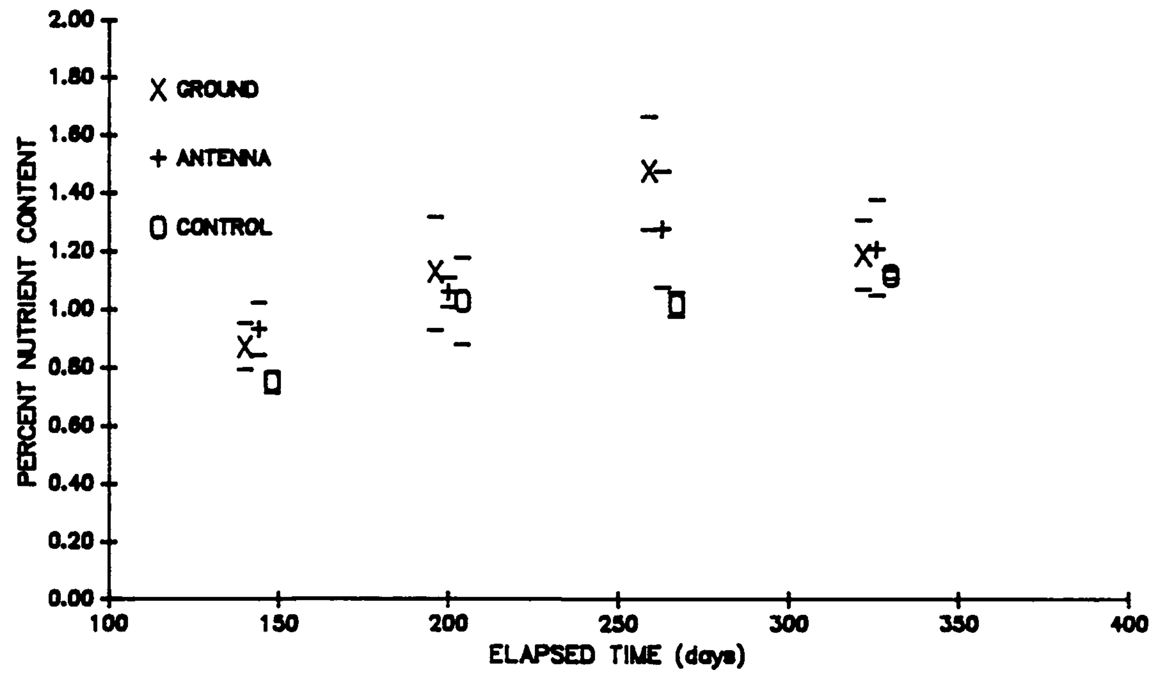


FIGURE 60. Percent nitrogen content of bulk oak leaf samples retrieved from the three plantation subunits during the 1987–1988 experiment.

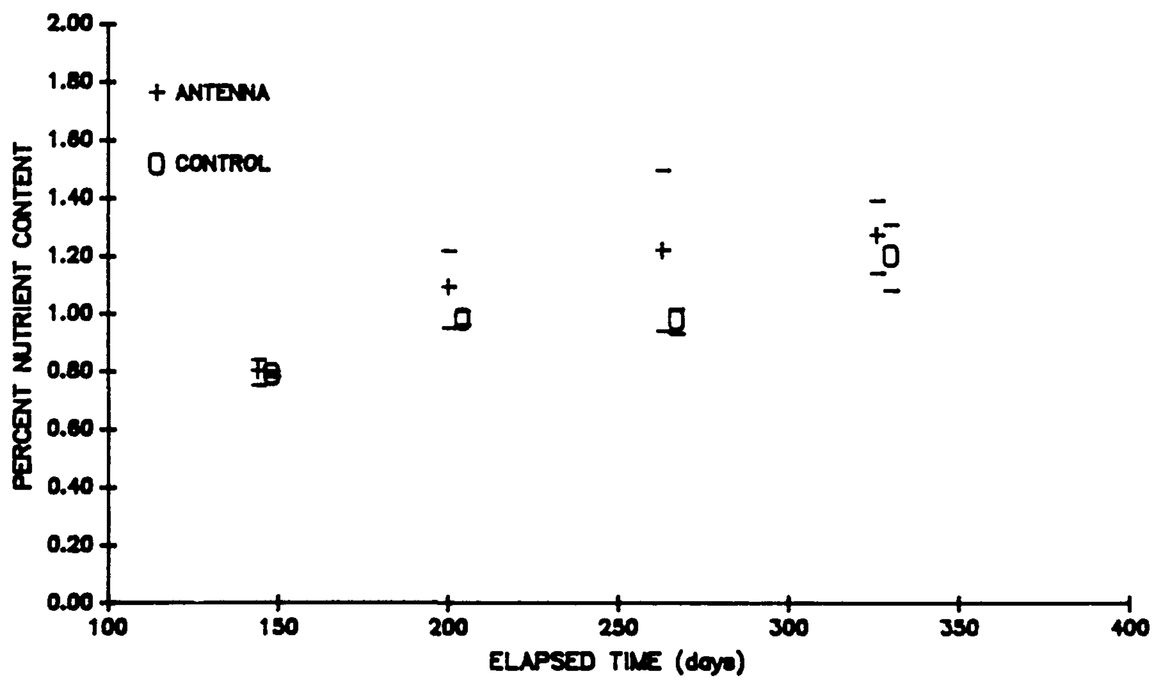


FIGURE 61. Percent nitrogen content of bulk oak leaf samples retrieved from the two hardwood stand subunits during the 1987–1988 experiment.

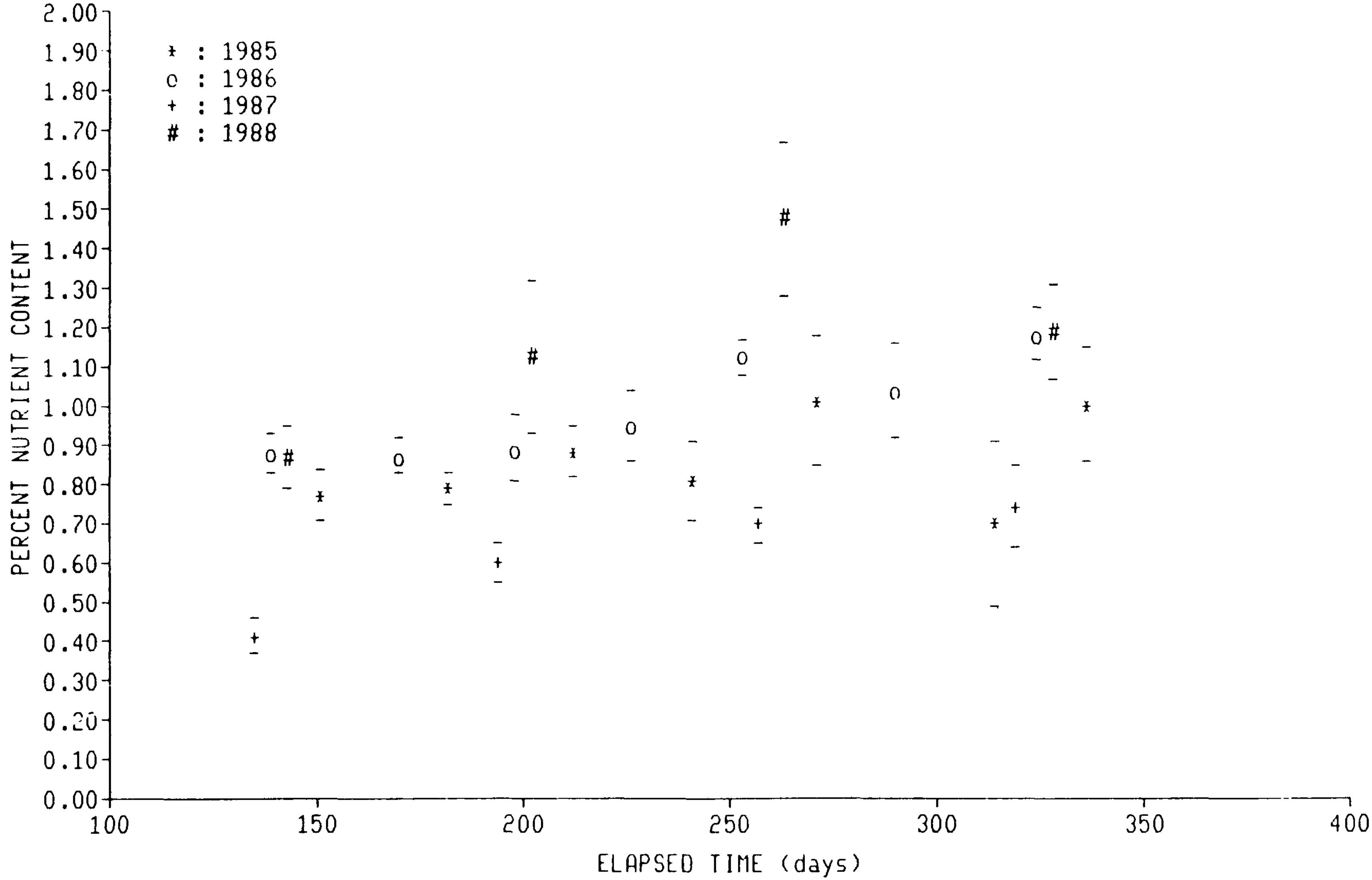


Figure 62. Percent nitrogen content of bulk oak leaf samples retrieved from the ground unit plantation during the four consecutive annual experiments analyzed to date.

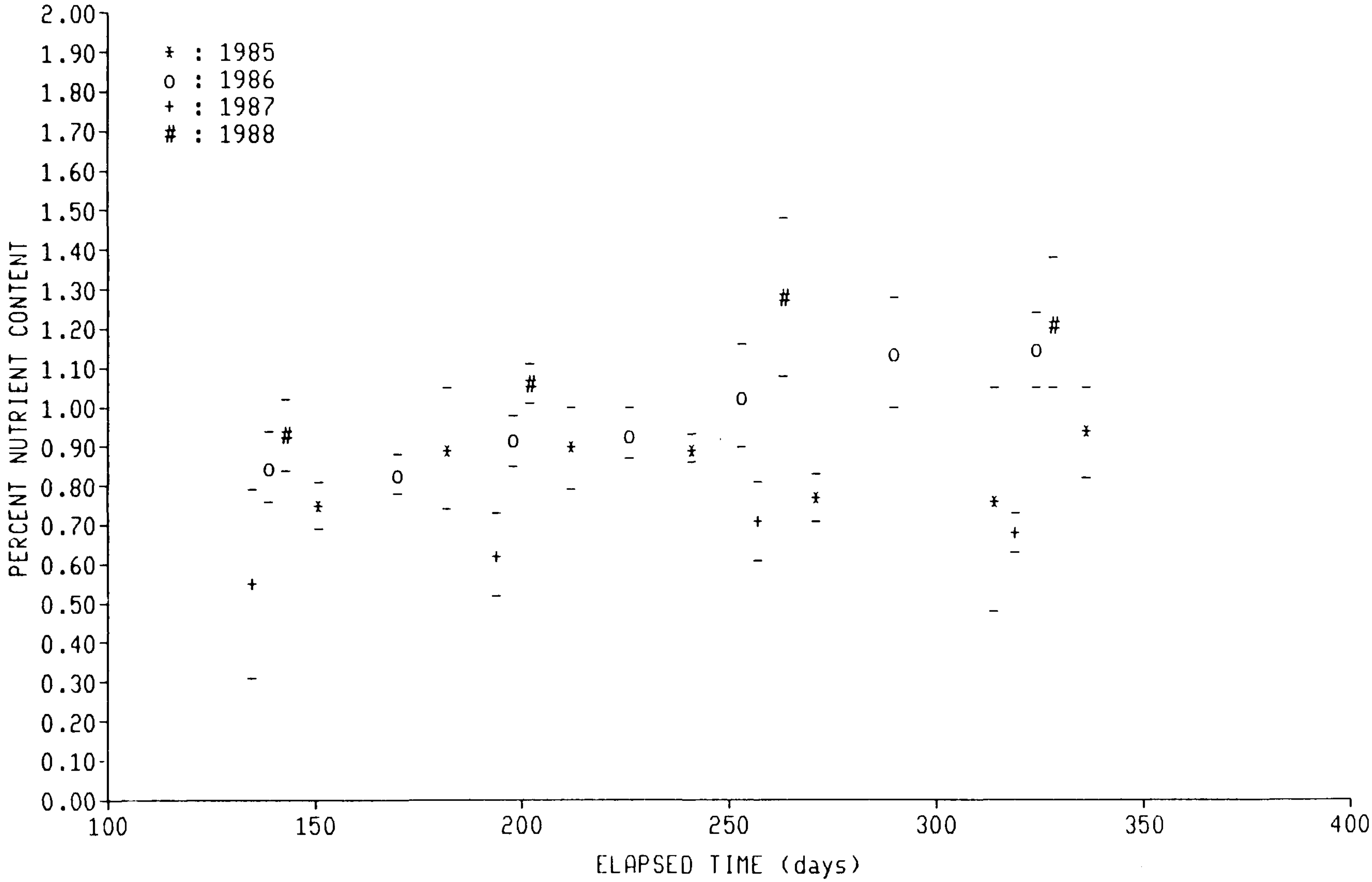


Figure 63. Percent nitrogen content of bulk oak leaf samples retrieved from the antenna unit plantation during the four consecutive annual experiments analyzed to date.

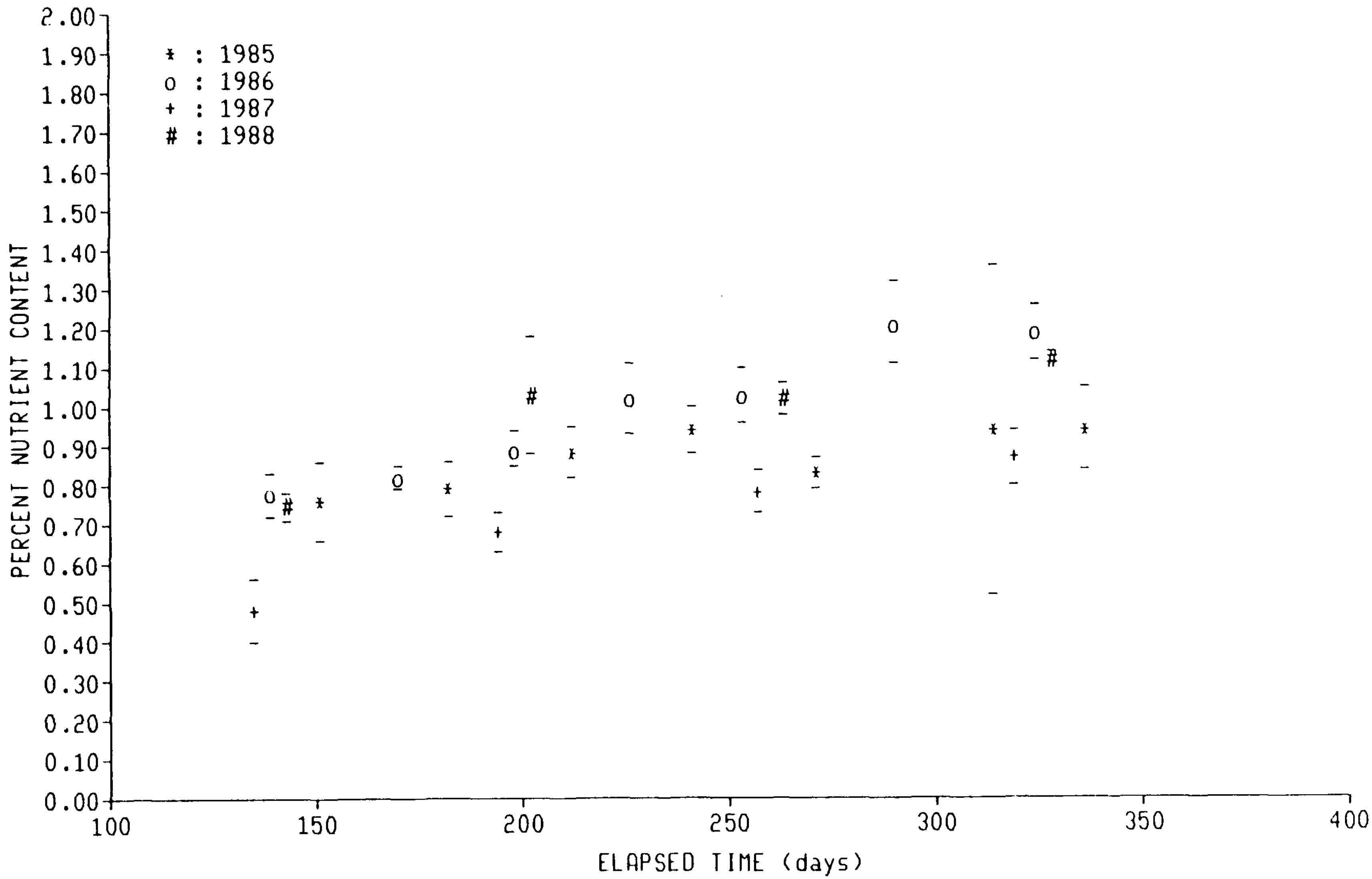


Figure 64. Percent nitrogen content of bulk oak leaf samples retrieved from the control unit plantation during the four consecutive annual experiments analyzed to date.

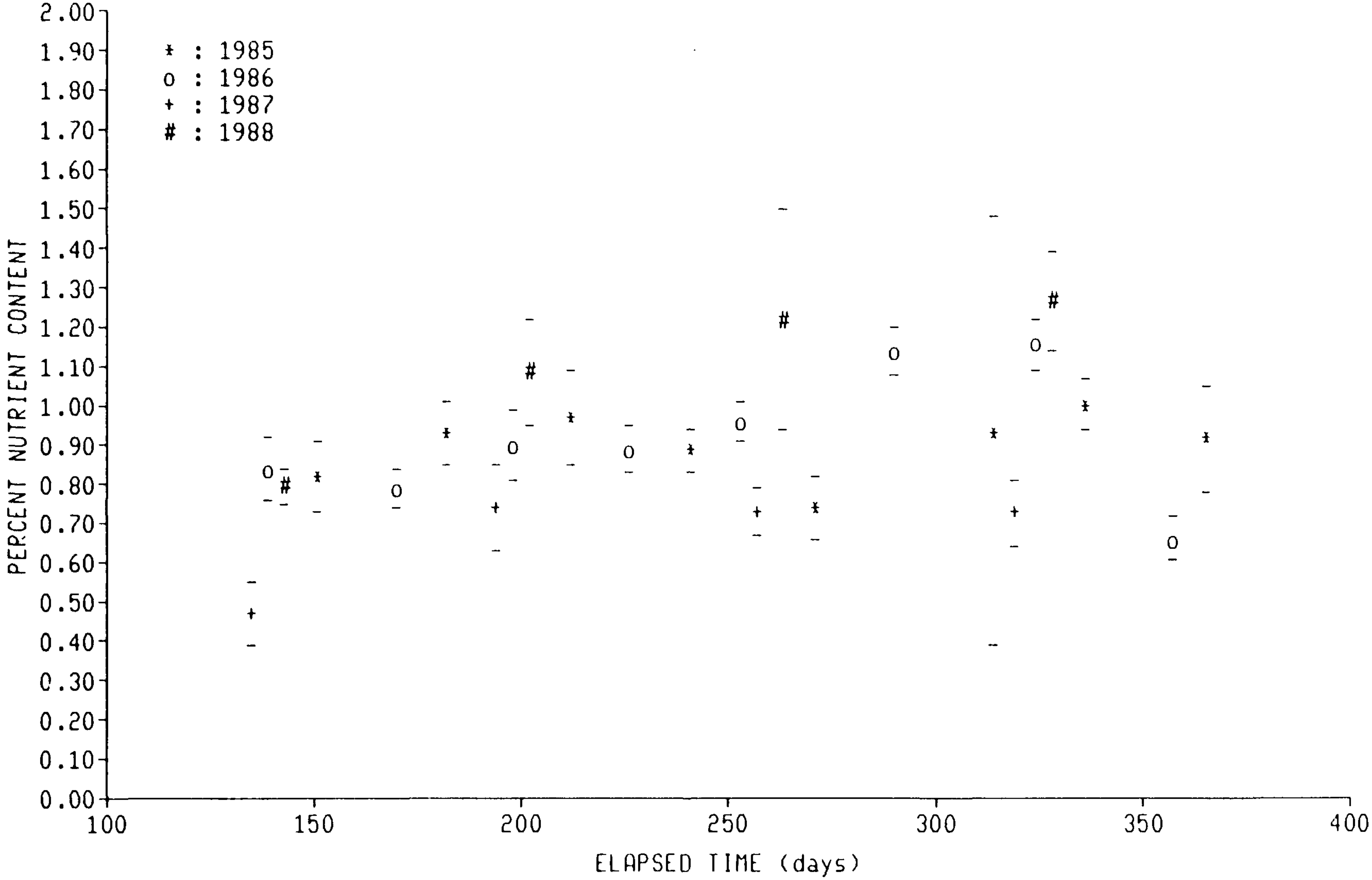


Figure 65. Percent nitrogen content of bulk oak leaf samples retrieved from the antenna unit hardwood stand during the four consecutive annual experiments analyzed to date.

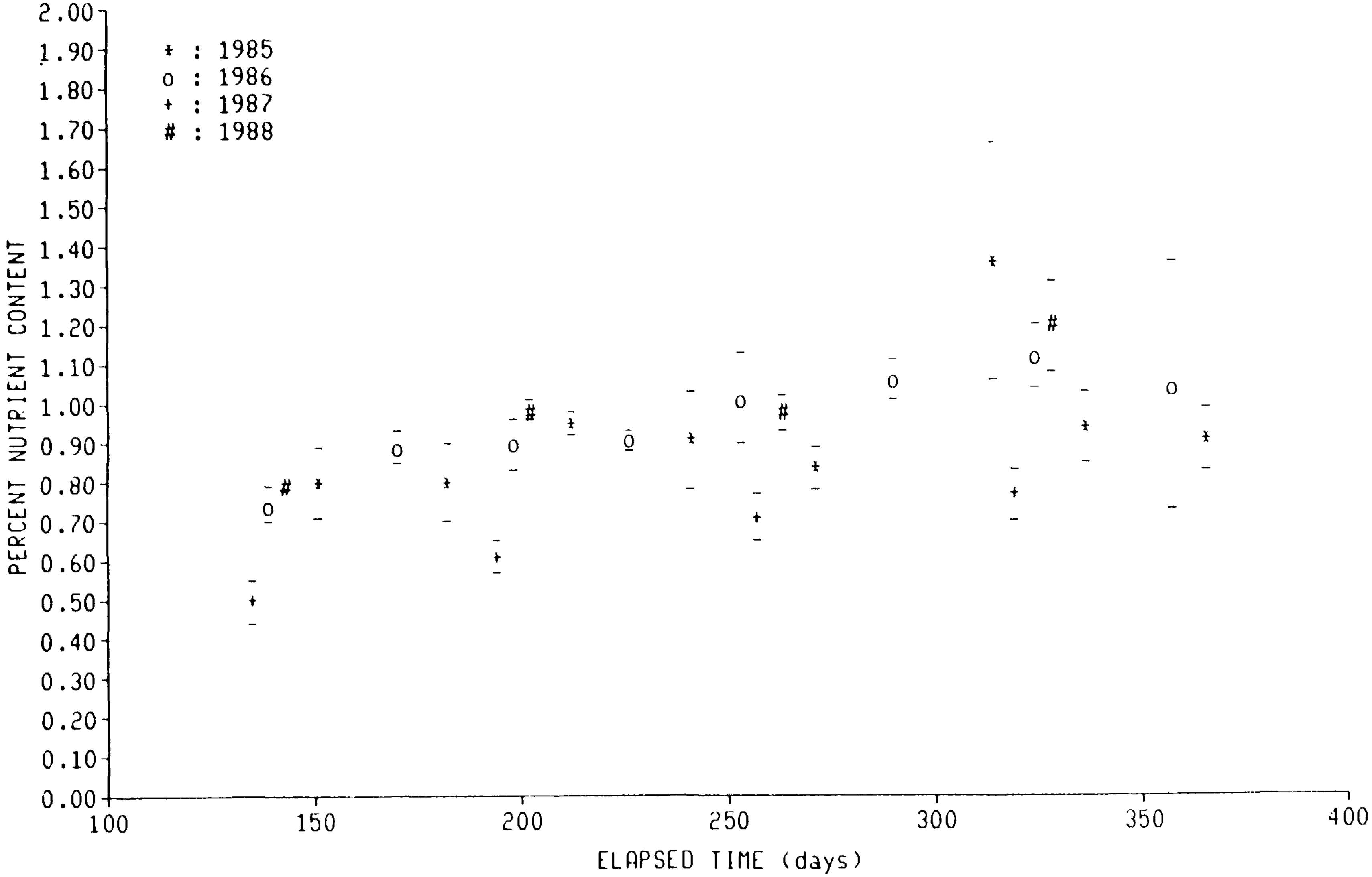


Figure 66. Percent nitrogen content of bulk oak leaf samples retrieved from the control unit hardwood stand during the four consecutive annual experiments analyzed to date.

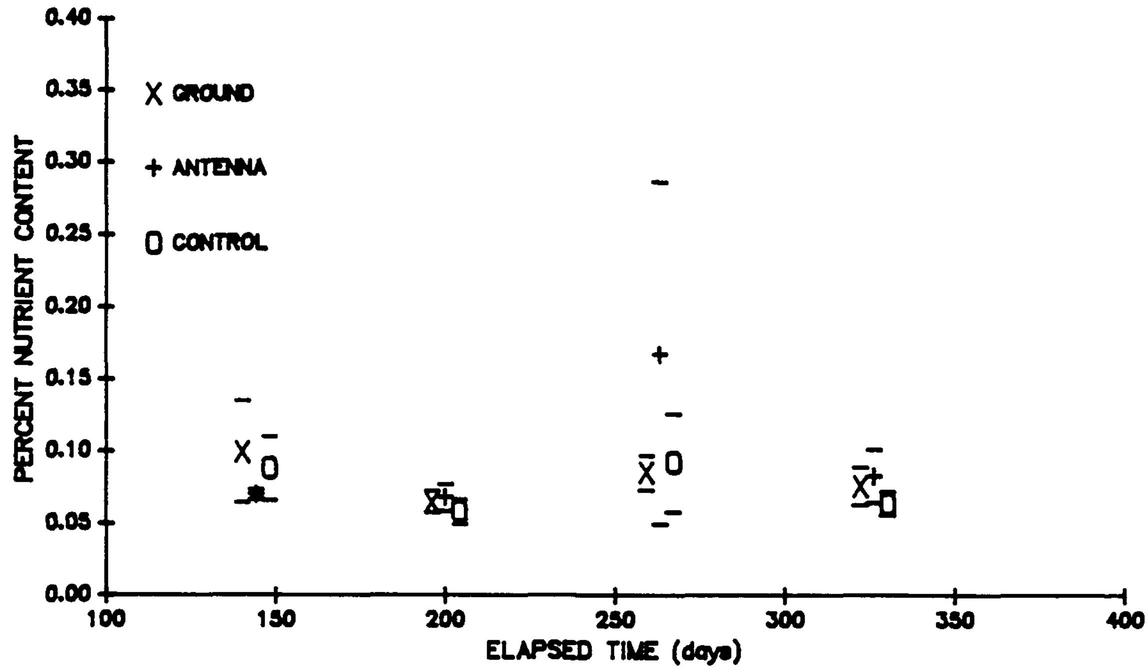


FIGURE 67. Percent phosphorus content of bulk oak leaf samples retrieved from the three plantation subunits during the 1987–1988 experiment.

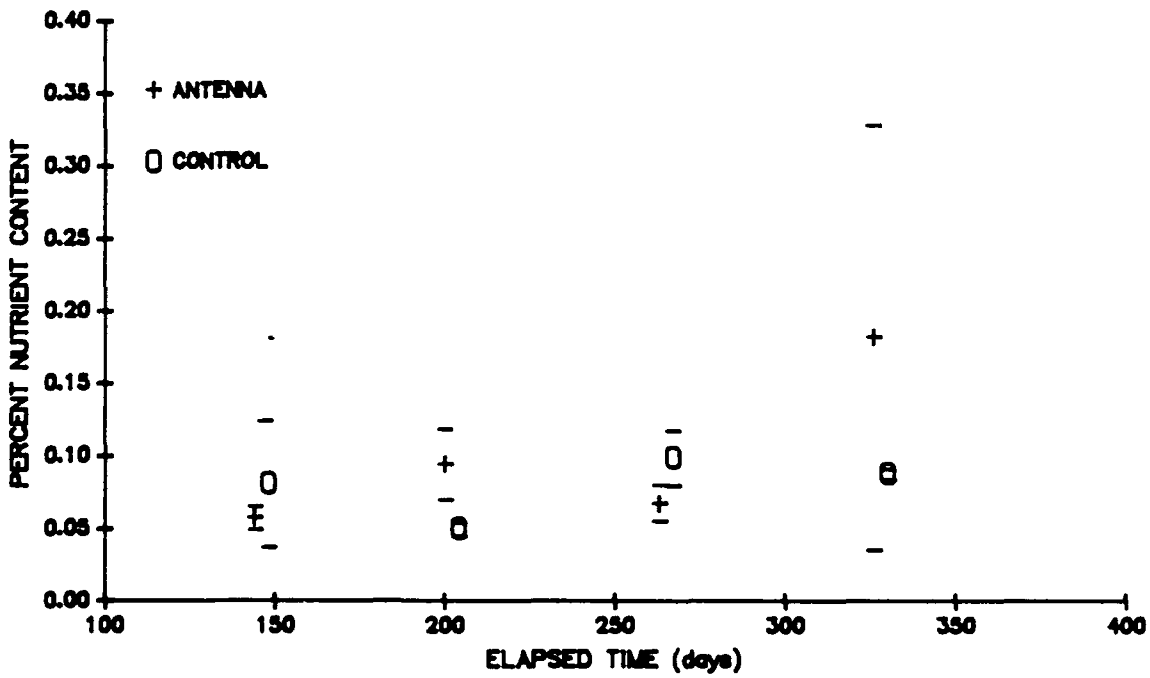


FIGURE 68. Percent phosphorus content of bulk oak leaf samples retrieved from the two hardwood stand subunits during the 1987–1988 experiment.

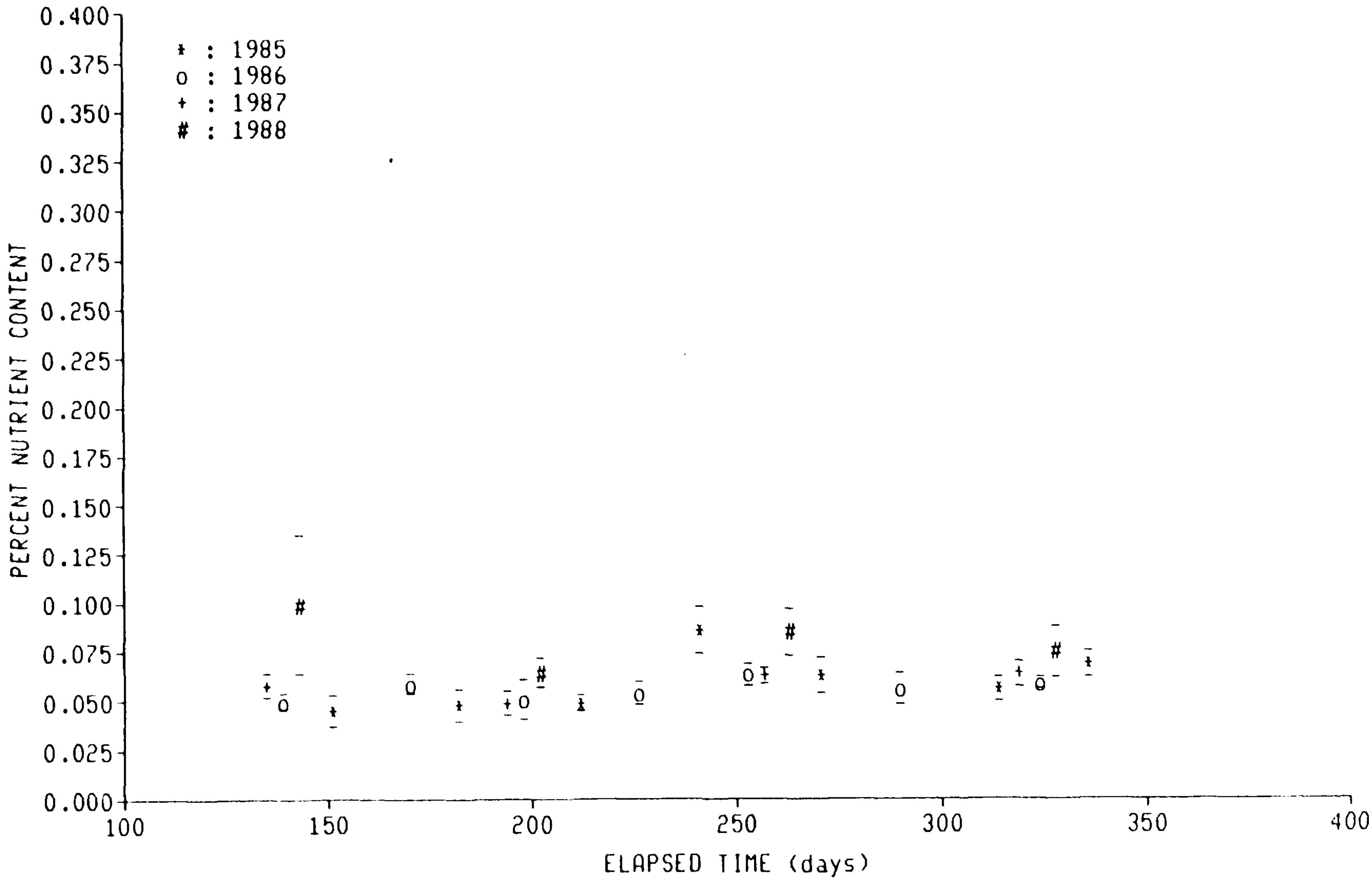


Figure 69. Percent phosphorus content of bulk oak leaf samples retrieved from the ground unit plantation during the four consecutive annual experiments analyzed to date.

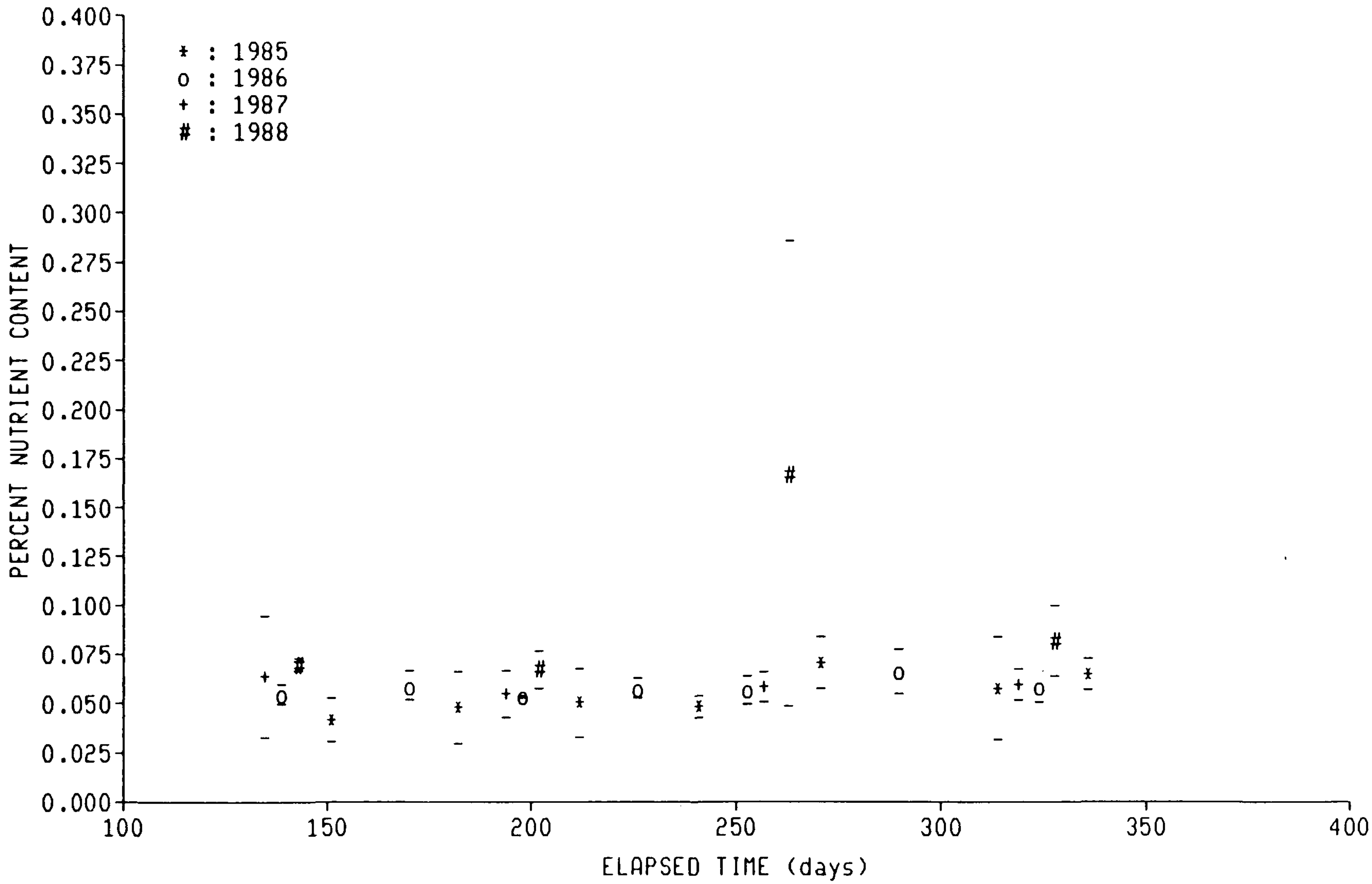


Figure 70. Percent phosphorus content of bulk oak leaf samples retrieved from the antenna unit plantation during the four consecutive annual experiments analyzed to date.

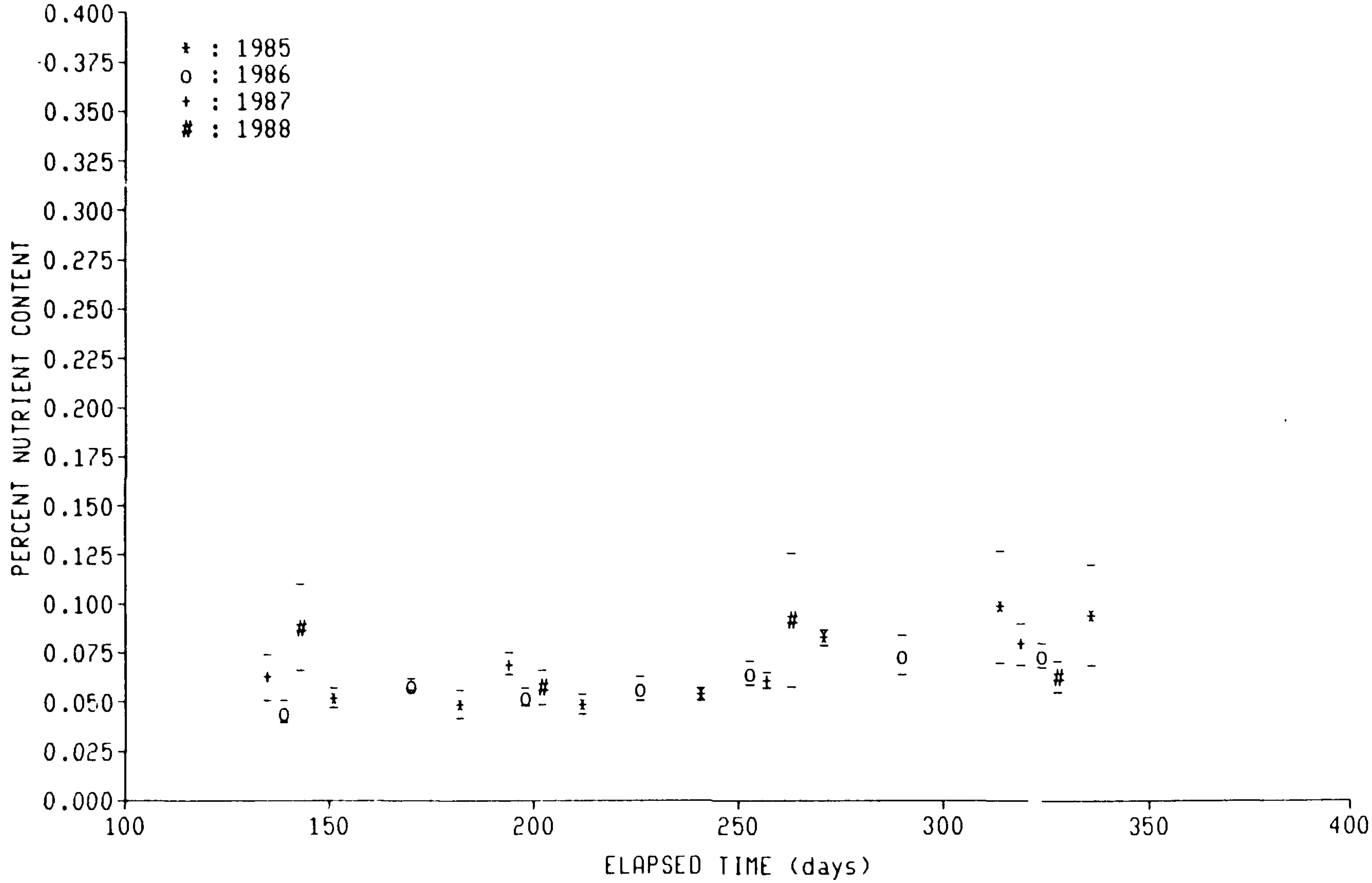


Figure 71. Percent phosphorus content of bulk oak leaf samples retrieved from the control unit plantation during the four consecutive annual experiments analyzed to date.

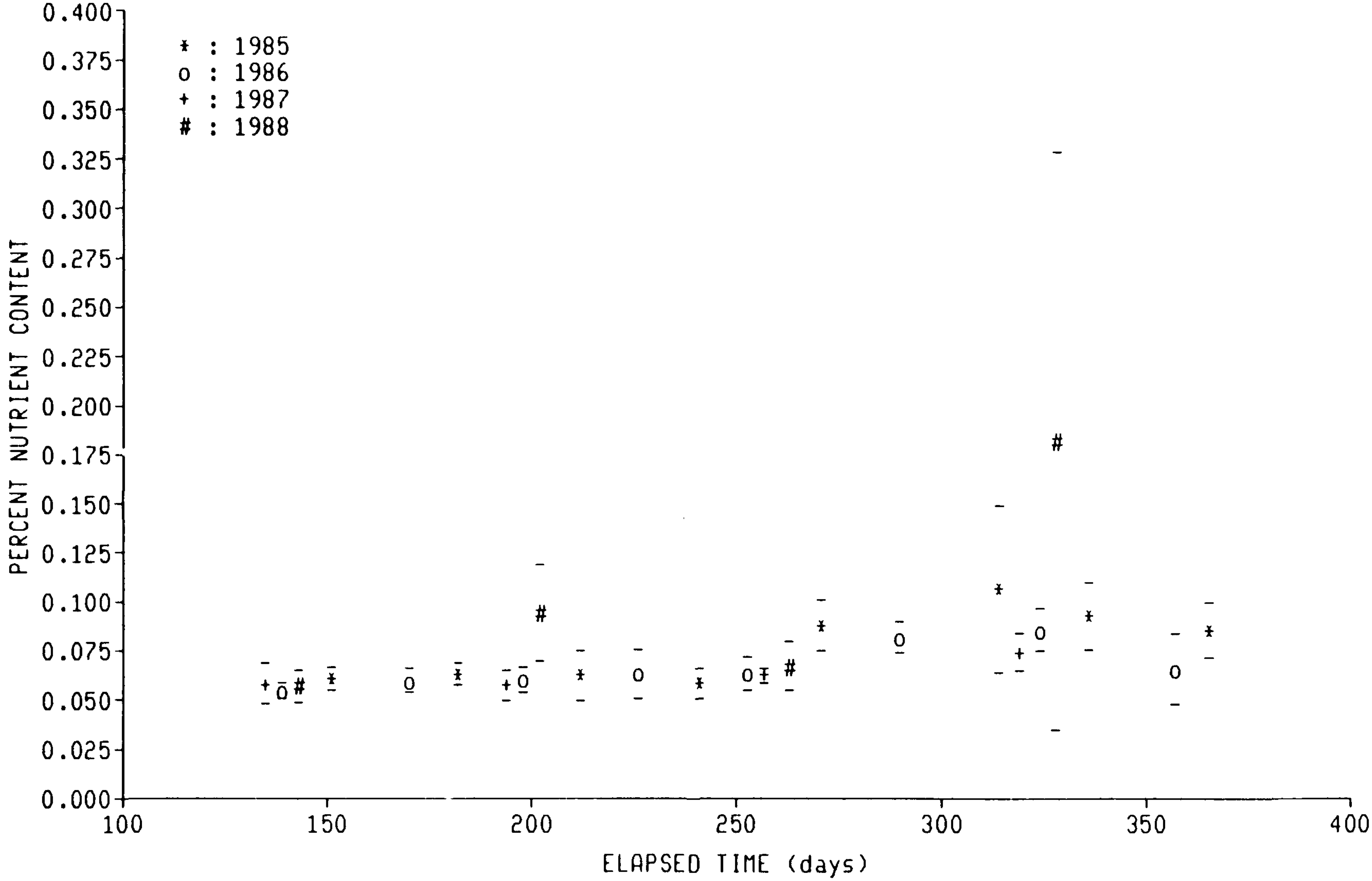


Figure 72. Percent phosphorus content of bulk oak leaf samples retrieved from the antenna unit hardwood stand during the four consecutive annual experiments analyzed to date.

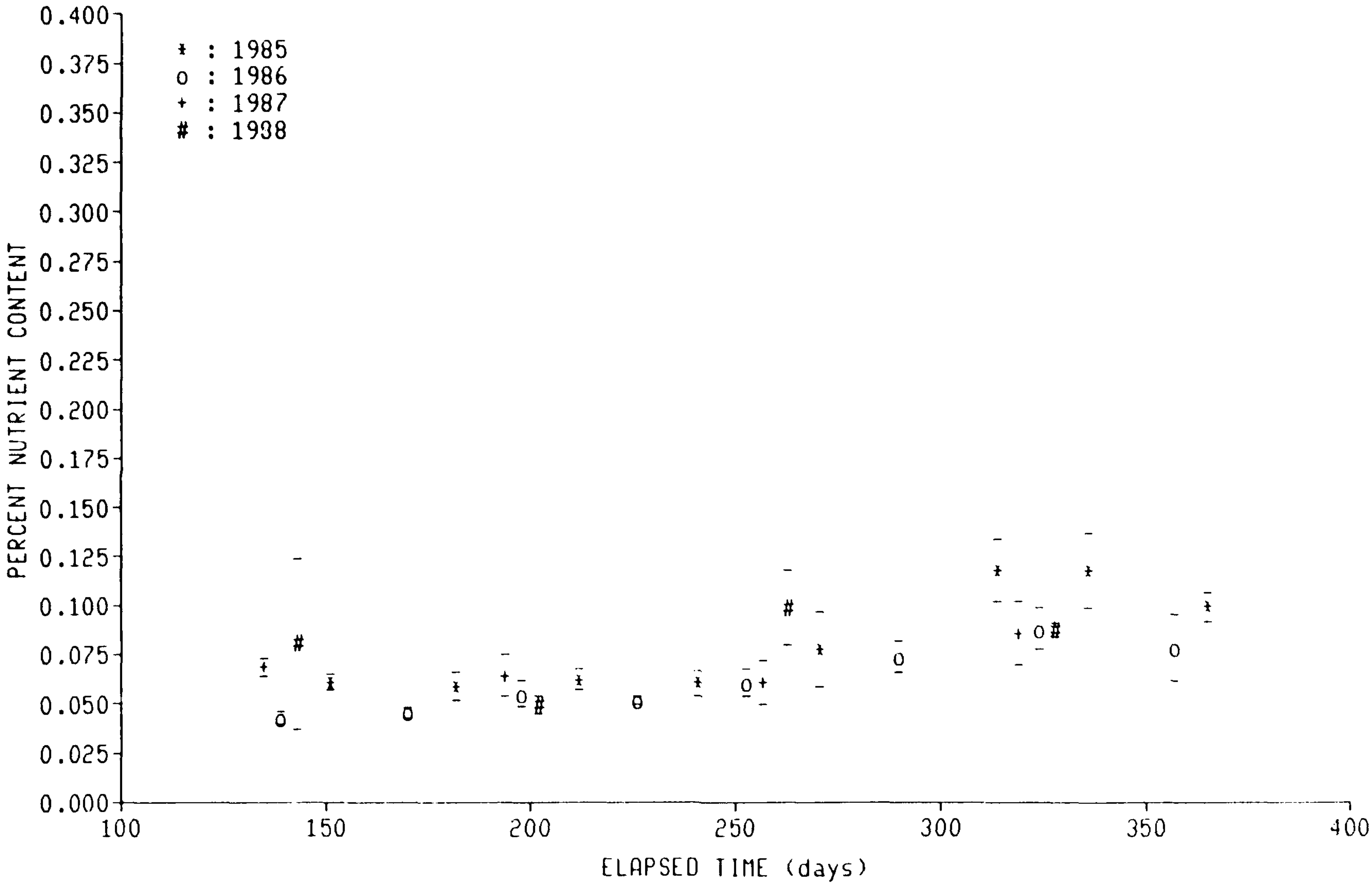


Figure 73. Percent phosphorus content of bulk oak leaf samples retrieved from the conrtol unit hardwood stand during the four consecutive annual experiments analyzed to date.

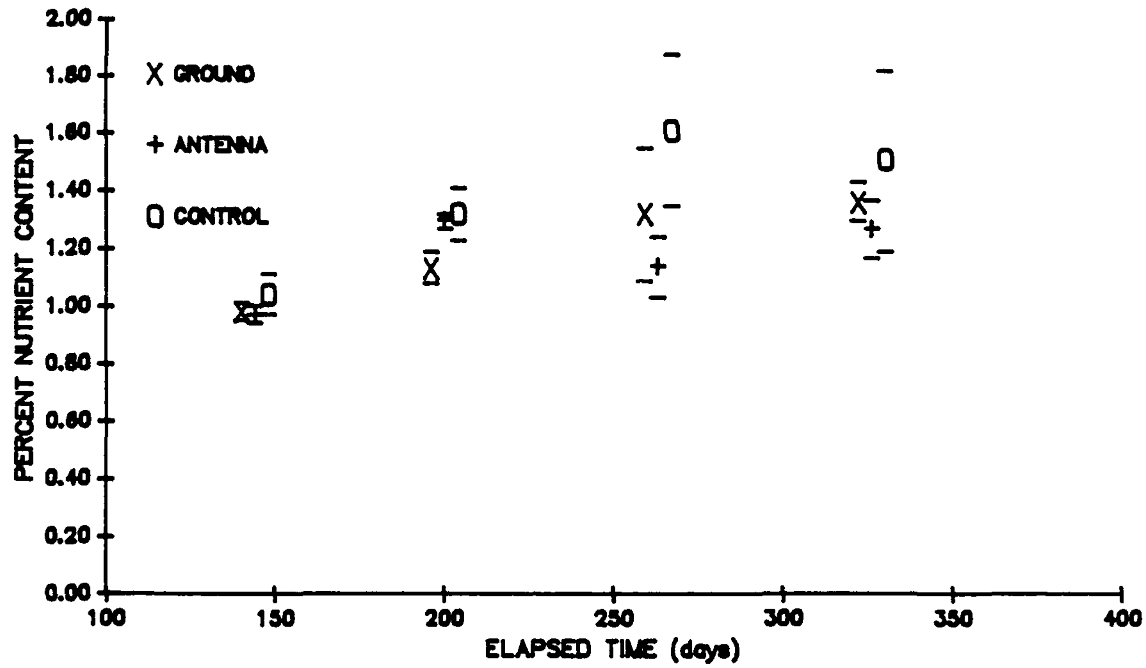


FIGURE 74. Percent nitrogen content of bulk maple leaf samples retrieved from the three plantation subunits during the 1987–1988 experiment.

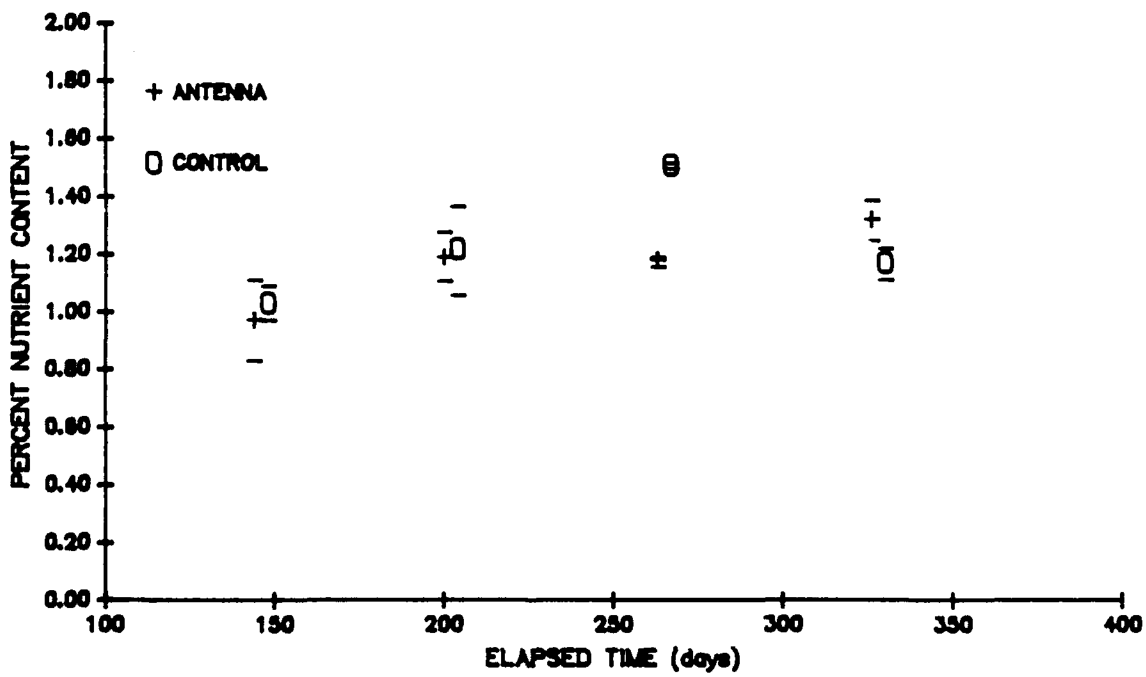


FIGURE 75. Percent nitrogen content of bulk maple leaf samples retrieved from the two hardwood stand subunits during the 1987–1988 experiment.

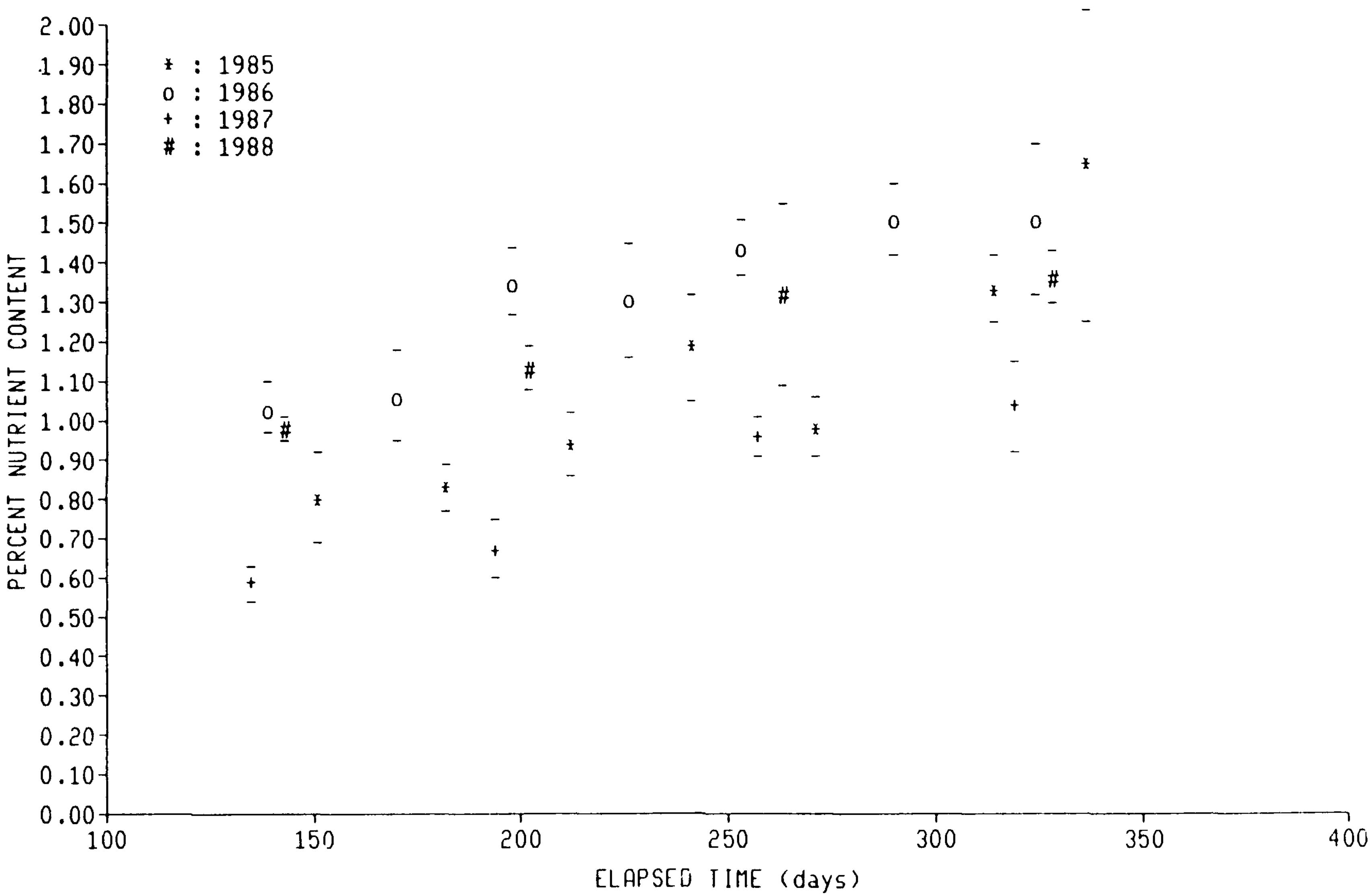


Figure 76. Percent nitrogen content of bulk maple leaf samples retrieved from the ground unit plantation during the four consecutive annual experiments analyzed to date.

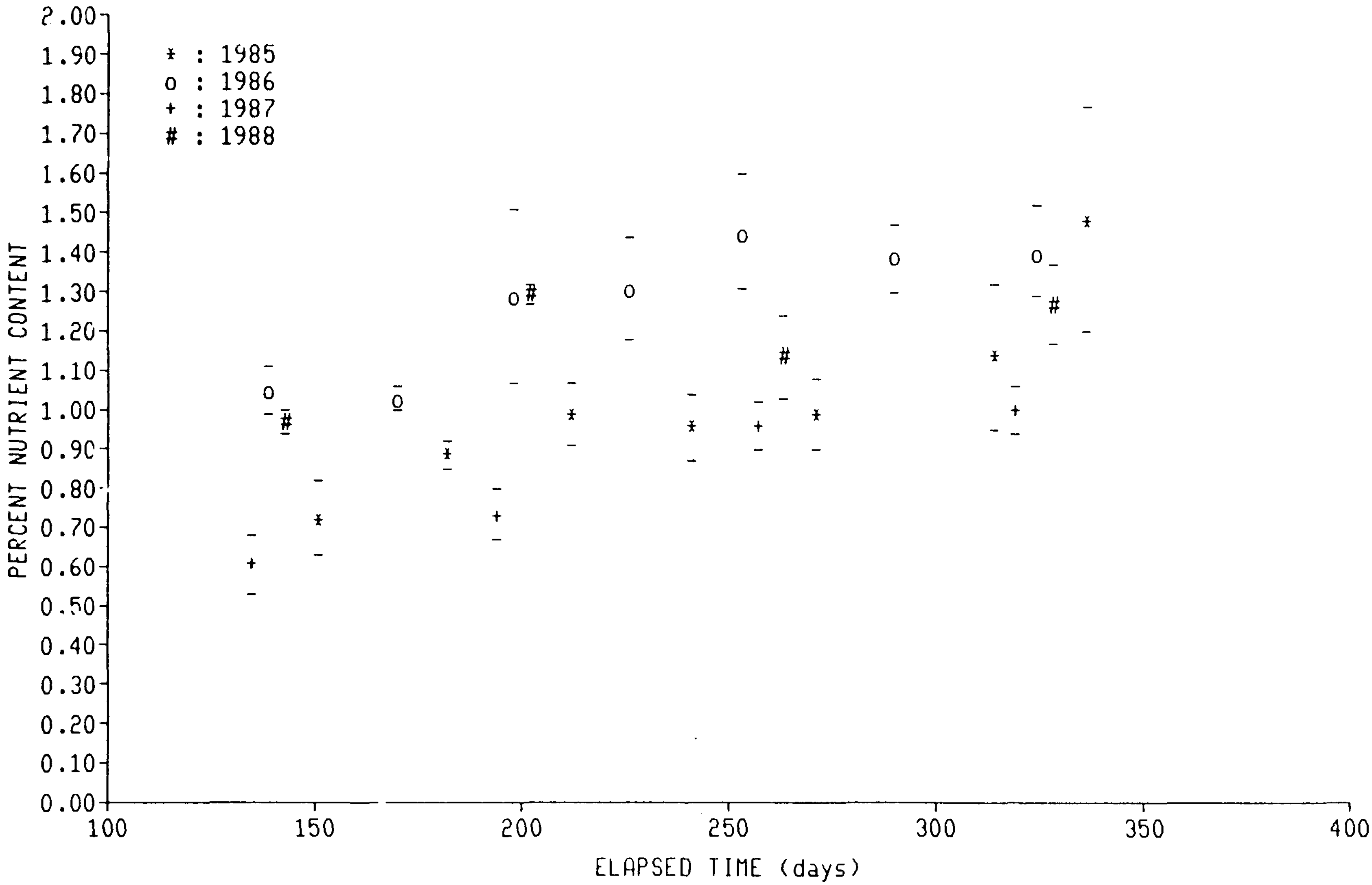


Figure 77. Percent nitrogen content of bulk maple leaf samples retrieved from the antenna unit plantation during the four consecutive annual experiments analyzed to date.

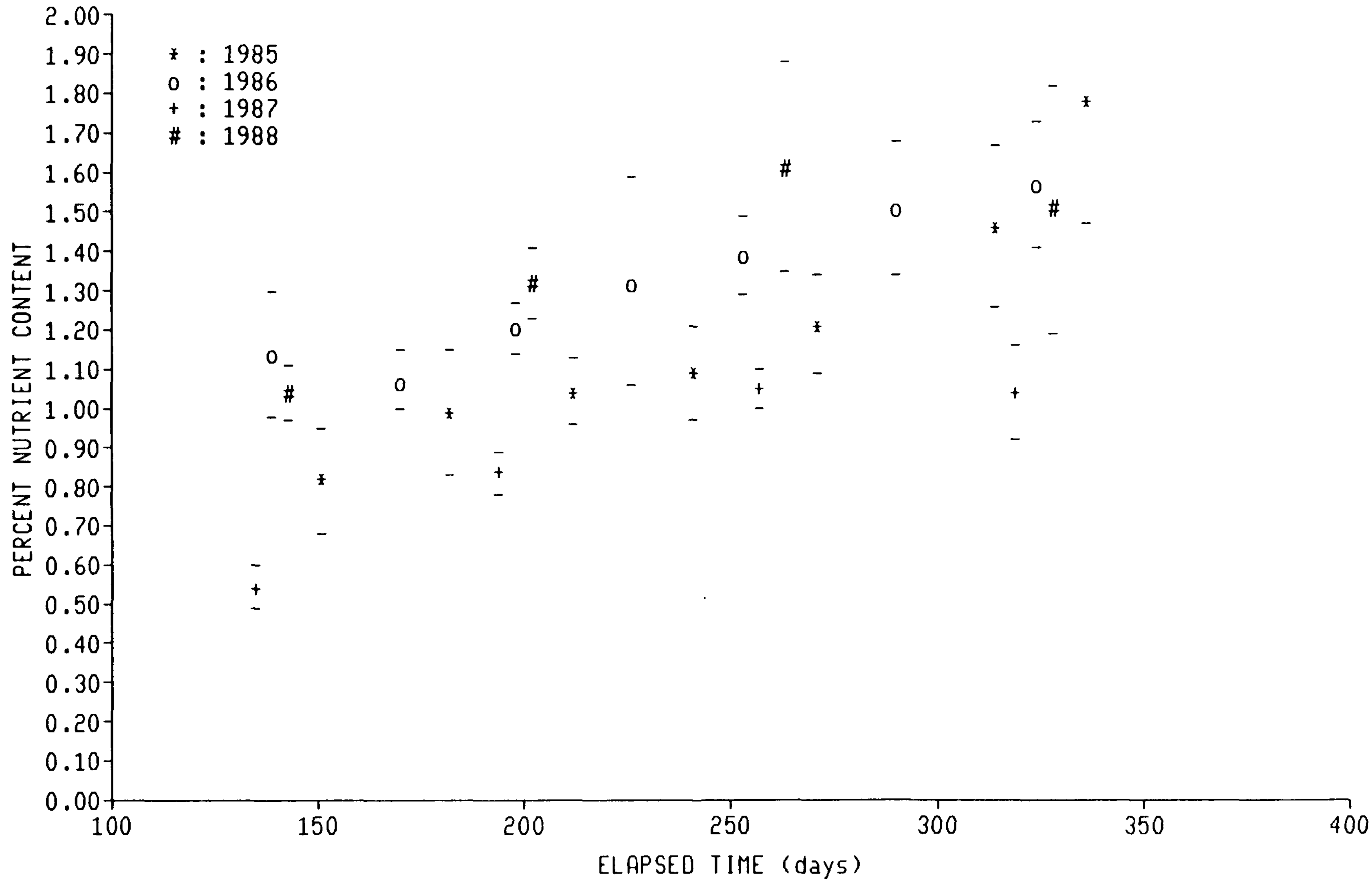


Figure 78. Percent nitrogen content of bulk maple leaf samples retrieved from the control unit plantation during the four consecutive annual experiments analyzed to date.

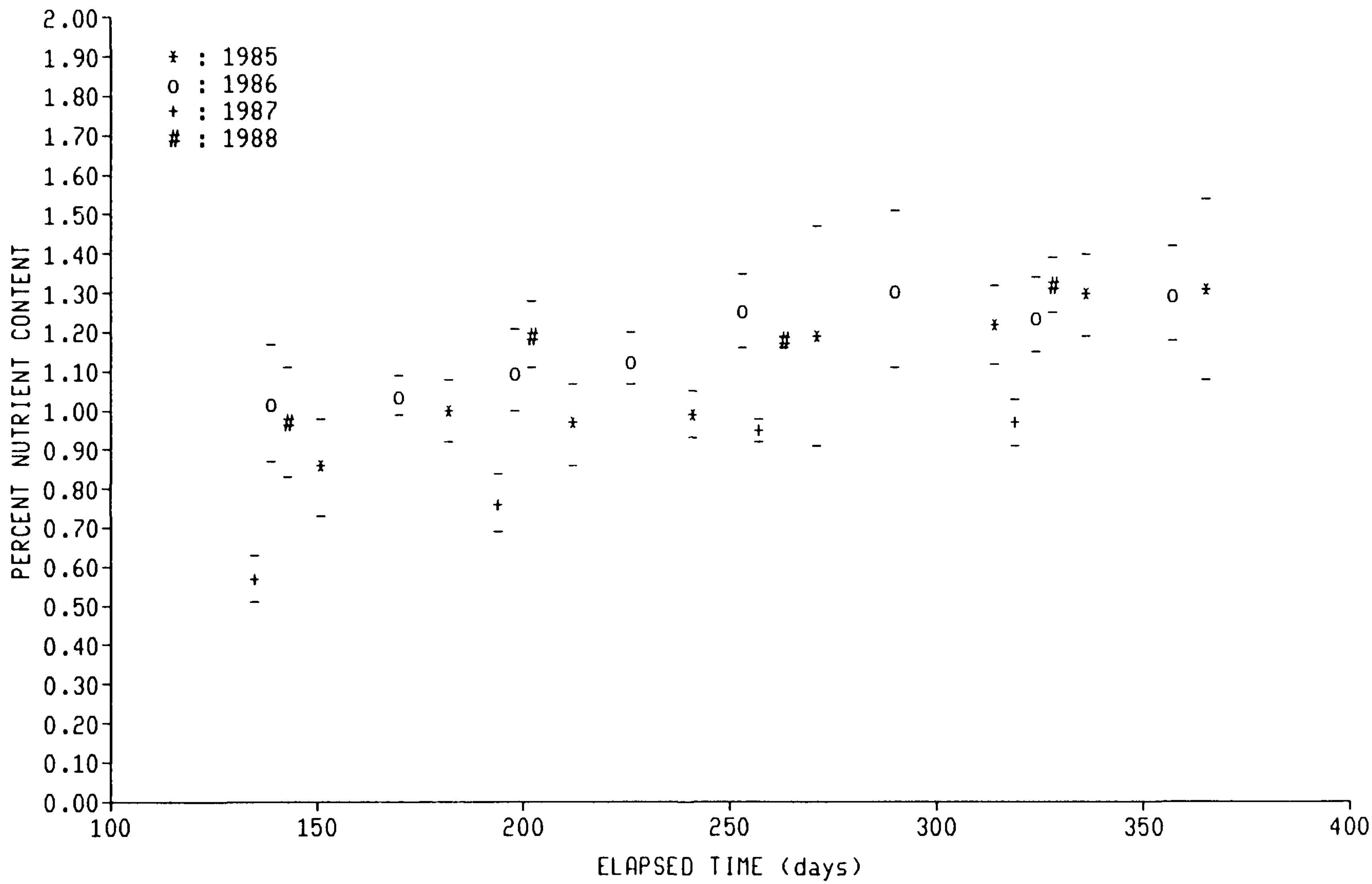


Figure 79. Percent nitrogen content of bulk maple leaf samples retrieved from the antenna unit hardwood stand during the four consecutive annual experiments analyzed to date.

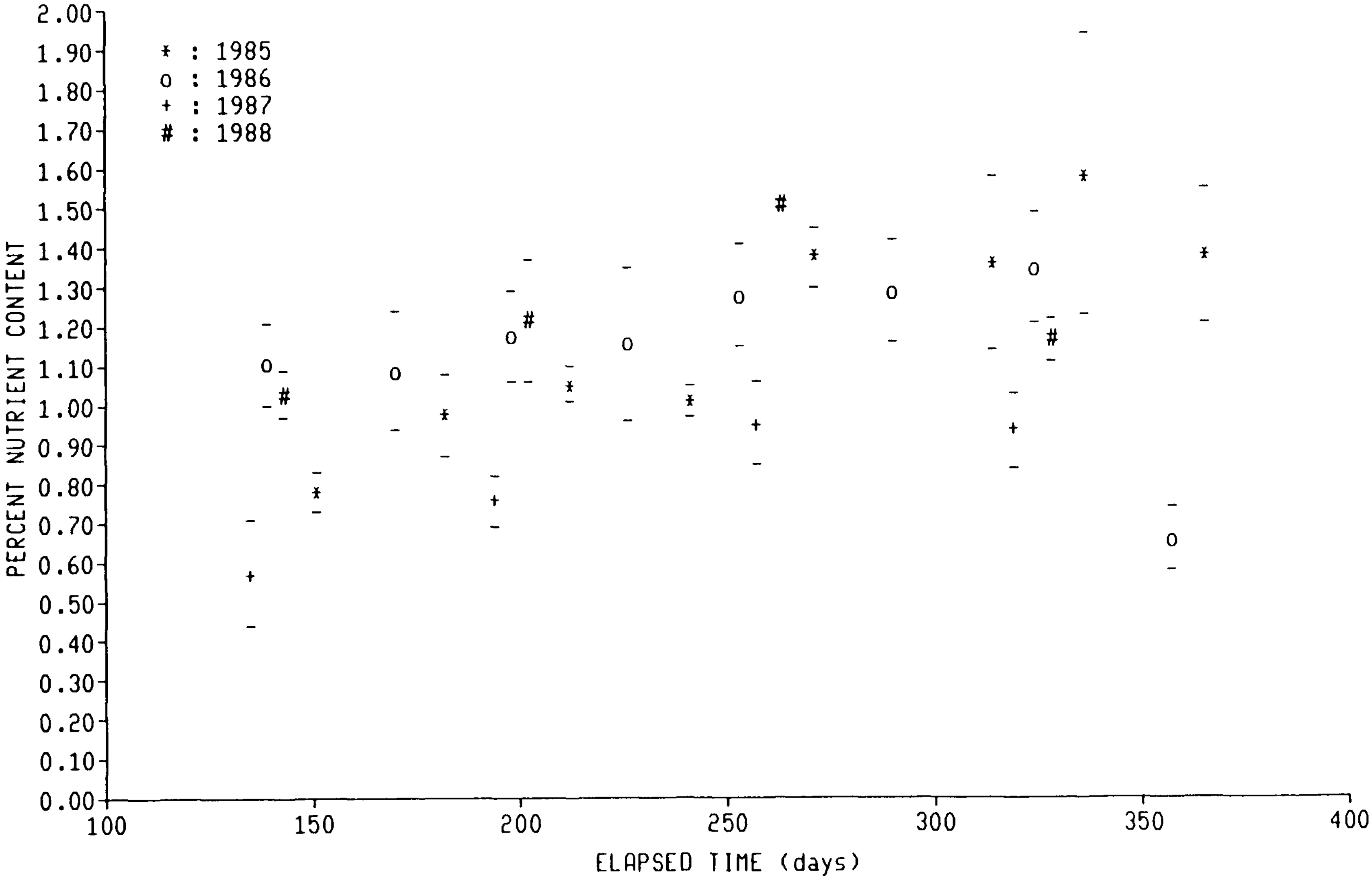


Figure 80. Percent nitrogen content of bulk maple leaf samples retrieved from the control unit hardwood stand during the four consecutive annual experiments analyzed to date.

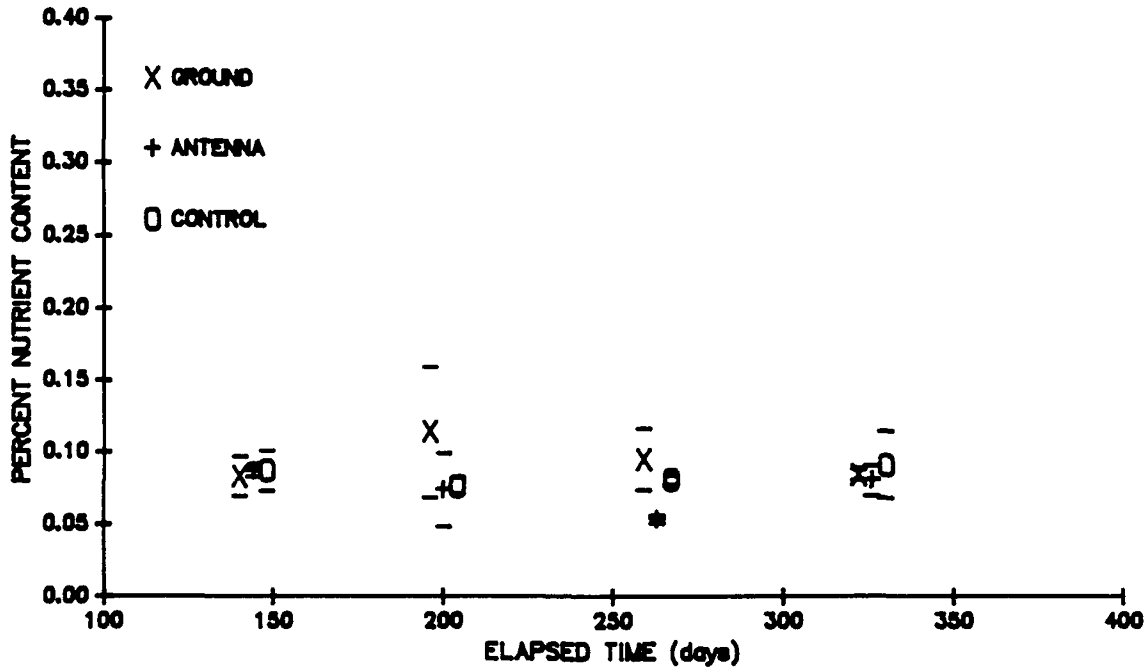


FIGURE 81. Percent phosphorus content of bulk maple leaf samples retrieved from the three plantation subunits during the 1987–1988 experiment.

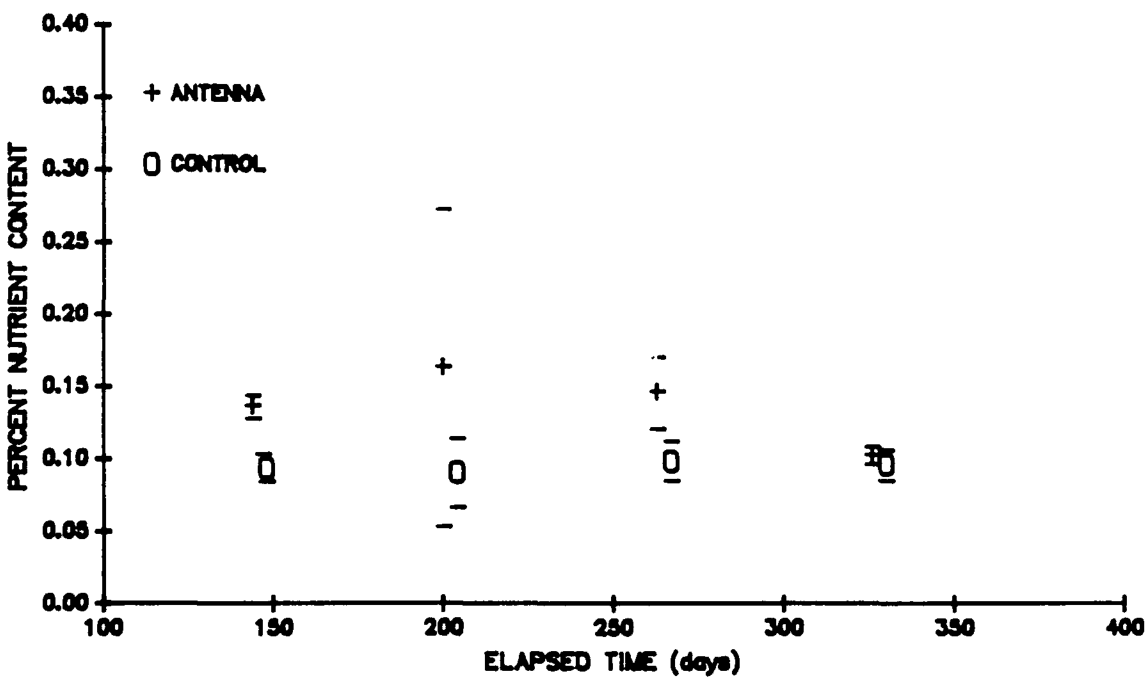


FIGURE 82. Percent phosphorus content of bulk maple leaf samples retrieved from the two hardwood stand subunits during the 1987–1988 experiment.

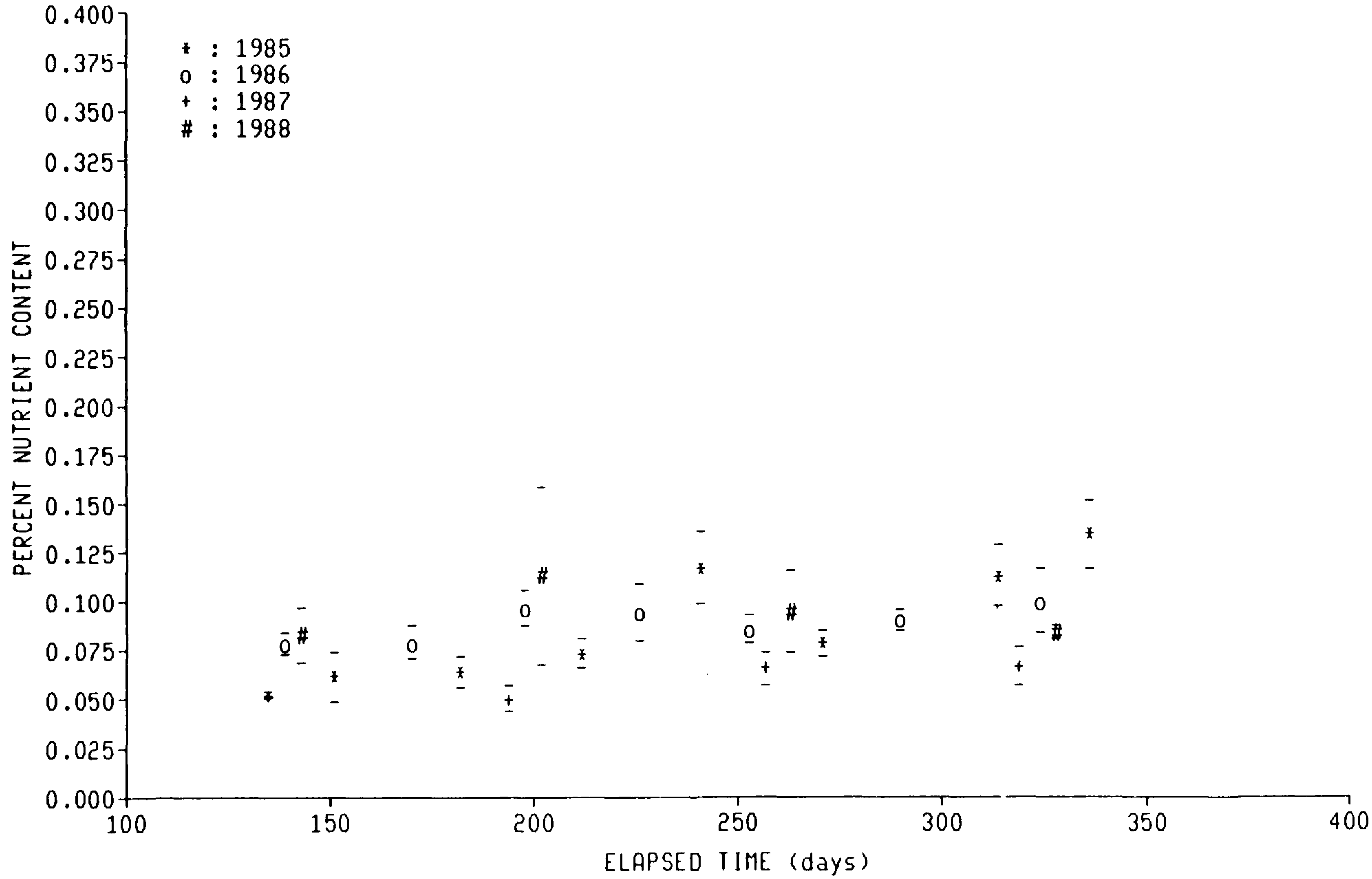


Figure 83. Percent phosphorus content of bulk maple leaf samples retrieved from the ground unit plantation during the four consecutive annual experiments analyzed to date.

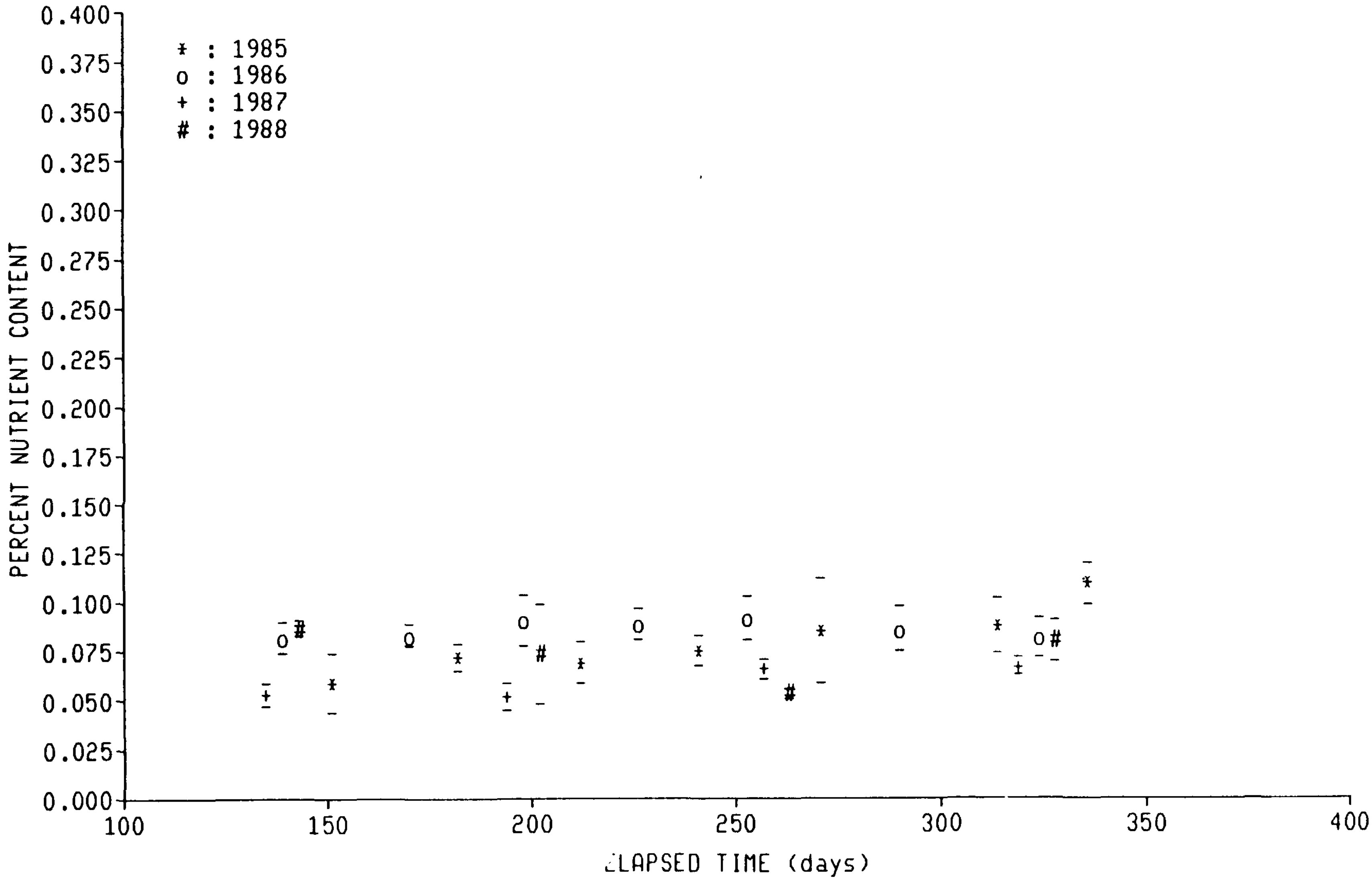


Figure 84. Percent phosphorus content of bulk maple leaf samples retrieved from the antenna unit plantation during the four consecutive annual experiments analyzed to date.

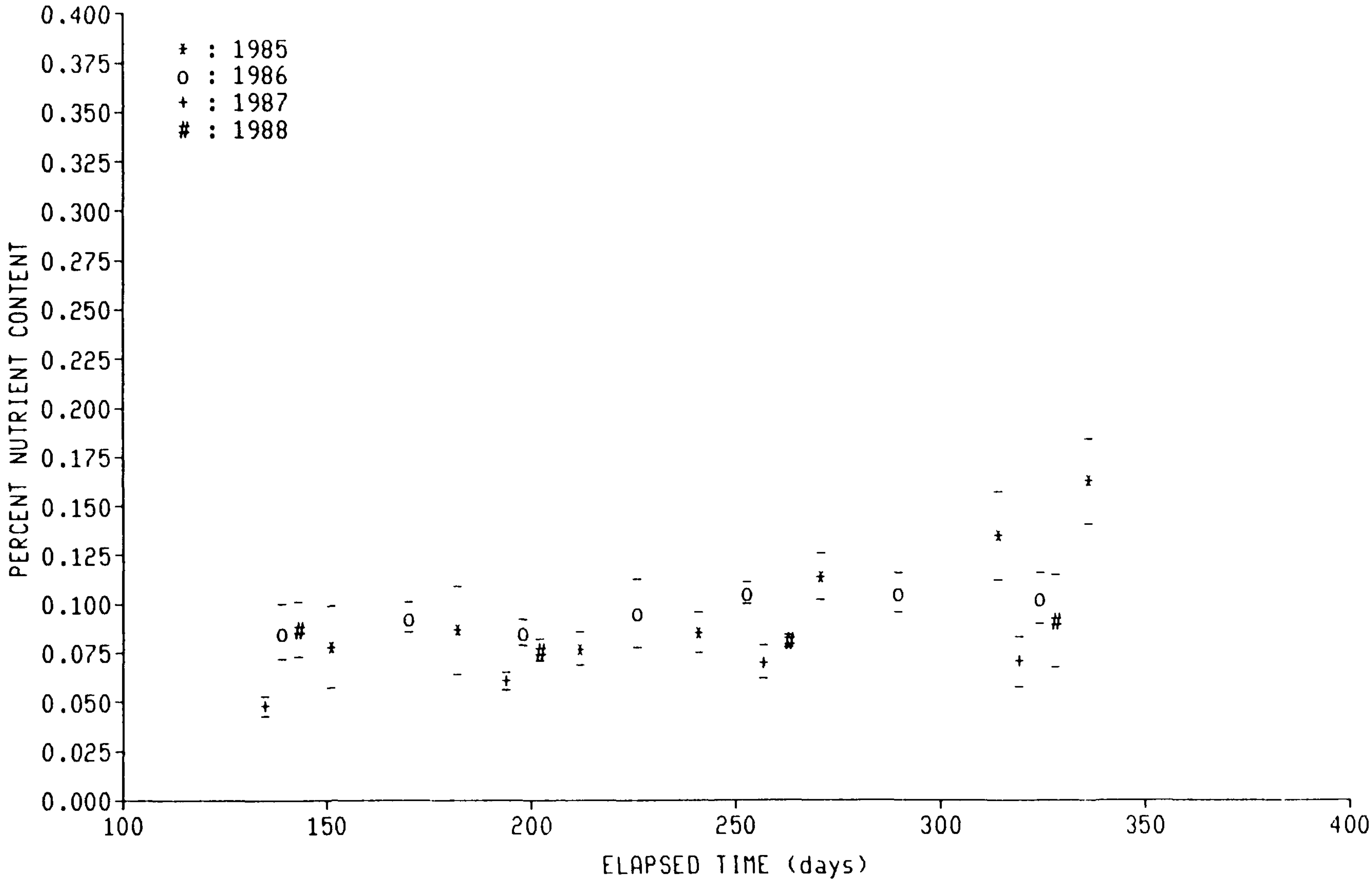


Figure 85. Percent phosphorus content of bulk maple leaf samples retrieved from the control unit plantation during the four consecutive annual experiments analyzed to date.

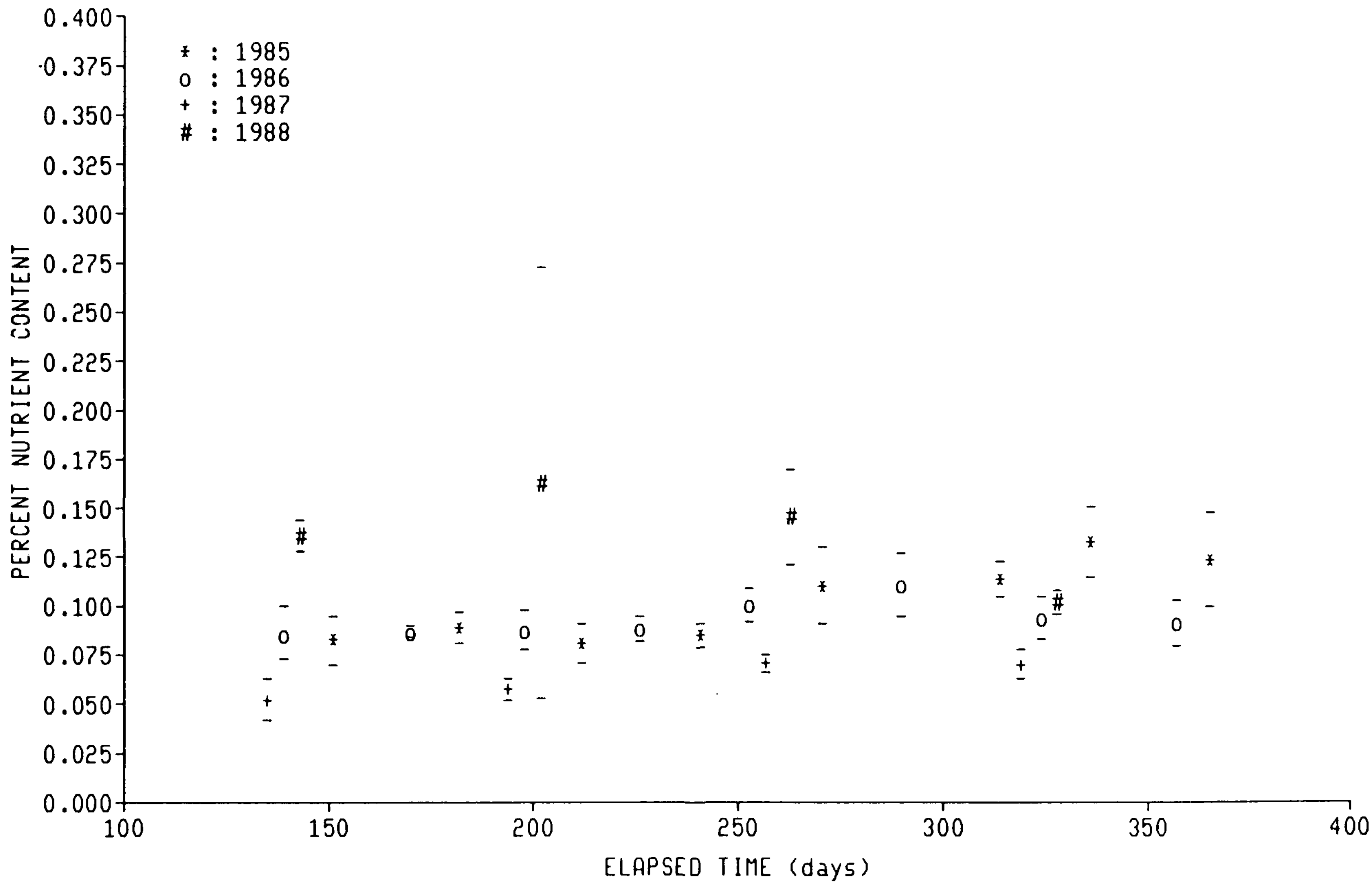


Figure 86. Percent phosphorus content of bulk maple leaf samples retrieved from the antenna unit hardwood stand during the four consecutive annual experiments analyzed to date.

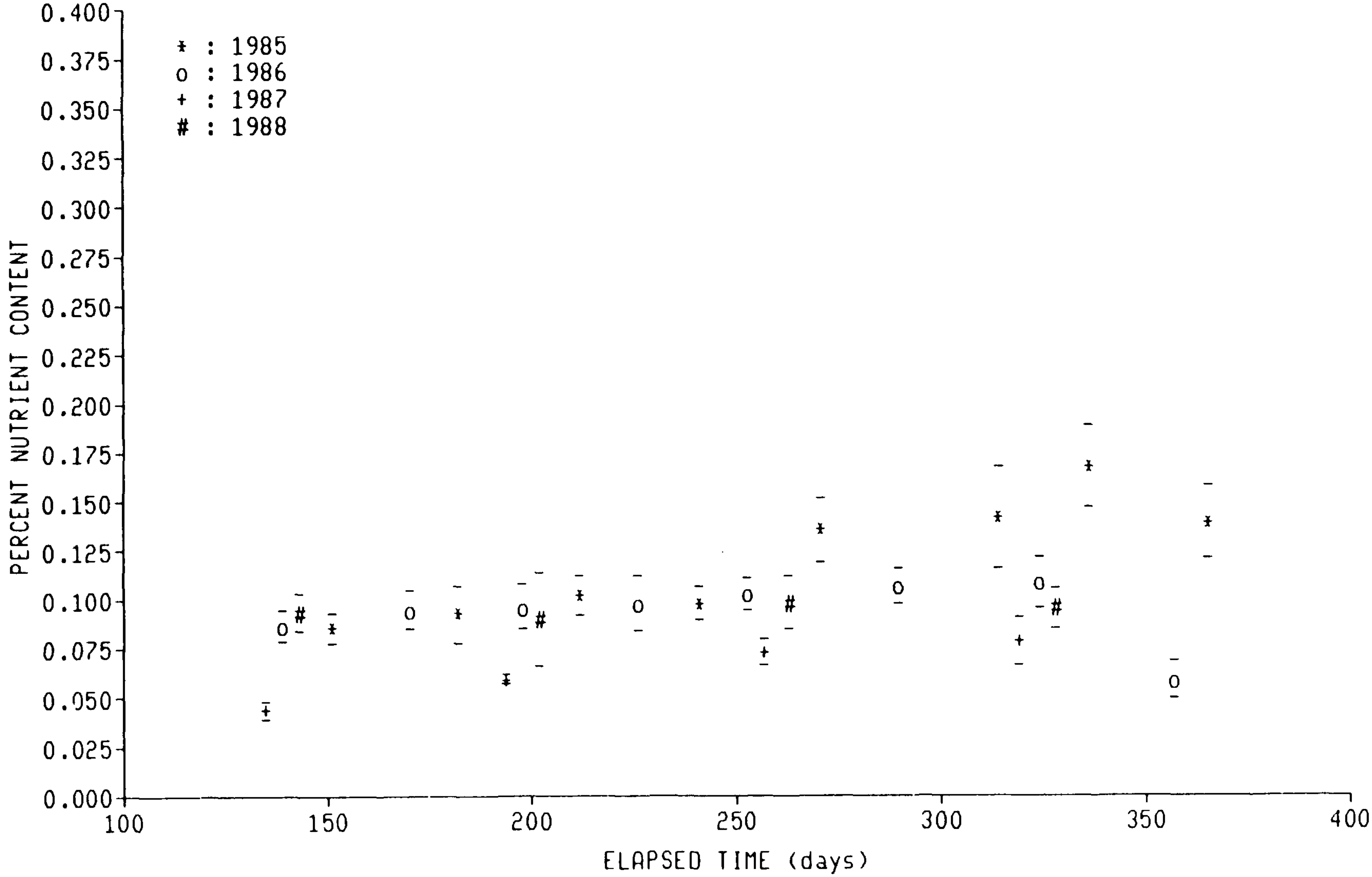


Figure 87. Percent phosphorus content of bulk maple leaf samples retrieved from the control unit hardwood stand during the four consecutive annual experiments analyzed to date.

Element 2: RED PINE SEEDLING RHIZOPLANE STREPTOMYCETES

Introduction

Streptomycetes have been implicated in the calcium and phosphorus nutrition of ectomycorrhizae and can influence mycorrhizosphere microbial population composition through production and excretion of compounds such as antibiotics, vitamins, amino acids, and hormones (Marx 1982, Keast and Tonkin 1983, Strzelczyk and Pokojska-Burdziej 1984, Strzelczyk et al. 1987). Streptomycetes have also been found to degrade calcium oxalate, cellulose, and lignin/lignocellulose in both coniferous and deciduous litter systems (Graustein et al. 1977, Crawford 1978, Knutson et al. 1980, Antai and Crawford 1981, McCarthy and Broda 1984). Mycorrhizal fungi are not capable of degrading either cellulose or lignin, though many saprotrophic soil-borne fungi are.

As part of the indigenous soil, rhizosphere, and rhizoplane microflora, populations of streptomycetes are not considered to undergo great population changes in stable ecosystems (Orchard 1984). Streptomycete populations functionally associated with the mycorrhizae of the planted red pine seedlings were therefore selected for inclusion in these long-term studies assessing potential impacts of ELF electromagnetic fields. As noted in the Introduction, the hypotheses to be tested are that there is no difference in the level or the seasonal pattern of mycorrhizoplane streptomycete populations or in the representation of different identifiable strains of mycorrhizoplane streptomycetes that cannot be explained using factors unaffected by ELF antenna operations.

The value of the red pine mycorrhiza studies being conducted by the Herbaceous Plant Cover and Tree Studies ("Trees") project is also greatly enhanced through quantitative study of the associated streptomycete populations. For instance, in cognate studies, we have found that in vitro growth rates of several common mycorrhizal fungus species are differentially affected by certain streptomycete morphotypes isolated from the mycorrhizoplane of ELF plantation red pine seedlings (Richter et al. 1989). Some of these same morphotypes also inhibit the growth of Armillaria spp., one of which causes the only fatal disease encountered so far among the plantation red pine seedlings.

The emphasis of this element during the 1989 sampling season continued to be the enumeration and characterization (into morphological types or morphotypes) of streptomycetes associated with the red pine mycorrhizal rhizoplane (i.e., washed mycorrhizal fine roots). As has been the case from 1985 through 1988, the mycorrhizal condition of red pine seedlings in the ground, antenna, and control site plantations has been followed on a monthly basis in 1989, from May through October, by staff of the "Trees" project. Samples of the red pine mycorrhizae collected and identified from each of the ELF study red pine plantations were provided to this study for analysis of streptomycete population dynamics. Detailed information on the

1989 red pine seedling mycorrhiza populations can be found in the 1989 Draft Annual Report of the "Trees" project (Element 4, Mycorrhizae Characterization and Root Growth, pages 156-167). The numbers of mycorrhizae (both overall and Type 3) per gram of sampled red pine root weight in 1989 were lower than in 1985 through 1987, but were slightly higher than in 1988. ANOVA on the five-year data set did not detect any significant differences between sites in mycorrhizae per gram of sampled root (either total or type 3), nor was the year by site interaction significant. As in previous years, a single mycorrhiza morphology type, designated type 3, has been studied. Type 3 mycorrhizae continue to predominate in all three ELF study plantations, probably because they are most often caused by species of Laccaria and/or Thelephora which occur naturally both in the study area and in the nursery from which the seedlings were originally obtained.

As in previous years, the experimental design called for analysis of six washed root samples (for macerate plate counts) per month from each of the three ELF study site red pine plantations. In addition to comparing data among plantations and sampling dates, the streptomycete level and morphotype data obtained during the 1989 sampling season were compared to data obtained for 1985 through 1988. The capabilities of the streptomycete morphotypes recovered to degrade calcium oxalate, cellulose, and lignocellulose were also determined.

Methods

Six washed mycorrhizal red pine fine root samples were collected and prepared monthly from late May to late October at the ground, antenna, and control site ELF study plantations. Five seedlings are excavated per month on each of the three plots comprising each plantation. Two independent composite samples were derived from two to three of the seedlings from each plot. An exception occurred with the July, 1989, root samples; an error was made in the root preparation and only three samples per plantation were made available for testing. The same plantation plots were sampled in 1989 as in 1984 through 1988. These samples were stored at 4°C and processed within 12 hours of receipt by the Environmental Microbiology lab in the Department of Biological Sciences. Less than 9 days were usually required for processing of field samples from the time root samples were collected in the field to the delivery of washed root samples for streptomycete analysis. There were two exceptions to this protocol in 1989 due to a miscommunication with the new personnel in charge of sorting the red pine mycorrhizae. The September and October roots were not received until 15 and 22 days after sampling, respectively; they were processed immediately on receipt.

Using flame-sterilized forceps, 0.1 g (wet weight) of washed roots was placed in 9.9 ml of sterile buffer (0.01 M phosphate buffer, pH 7.2) and homogenized in a flame-sterilized 30 ml blender. This mixture was then transferred to a sterile, screw-cap test tube. Subsequent serial dilutions were made using

the same type of sterile buffer. Two larger portions of the washed roots (about 0.5 g each) were transferred to separate pre-weighed aluminum pans and weighed; these portions were then placed in a drying oven (60°C) for determination of dry weights.

As in the earlier studies, all washed root samples (after preparation and appropriate serial dilution) were spread-plated onto starch casein agar (SCA) in 100 x 15 mm petri dishes. Cycloheximide (50 mg/l) and nystatin (50 mg/l) were added to the SCA to prevent fungal growth (Andrews and Kennerly 1979, Goodfellow and Dawson 1978). Three dilutions (in duplicate) were spread-plated per sample. All plates were incubated at 20°C. Total numbers of streptomycete colonies were determined after 14 days incubation.

After enumeration, individual streptomycete colonies were characterized to determine the number of morphotypes per sample. All colonies with the same characteristics (i.e., presence/absence of diffusable pigment, presence/absence of aerial mycelium, color of aerial mycelium and any diffusable pigment, and reverse colony color) were considered to represent one morphological type or strain (Keast et al. 1984). Throughout the study, several colonies per streptomycete morphotype have been maintained in pure culture for further study. In order to evaluate the streptomycetes' potential contribution to mycorrhiza development and root growth, additional tests were conducted to evaluate degradation of calcium oxalate (Jayasuriya 1955, Knutson et al. 1980), cellulose (Smith 1977), and lignocellulose (Sutherland 1985). Both the numbers and identity (with respect to recurrence) of distinct streptomycete morphotypes found in the 1989 samples were compared to observations from similar samples for 1984 through 1988. This allowed us to determine if some of the same types are still present after the red pine seedlings have been in the field four years or more, and to determine whether the same types are present in all three ELF study site plantations.

Data for streptomycete levels and morphotype numbers, based on the SCA plate counts, were transformed to $\log_{10}$ for statistical analysis (Orchard 1984). All statistical analyses were conducted on the mainframe computer using PROC GLM of the Statistical Analysis System (SAS 1985). Two-way analysis of variance was used to compare sampling dates and study site plantations within 1989. Three-way analysis of variance was used to compare years (1985 through 1989), sampling dates (month), and plantations (Zar 1984). Wherever these analyses showed significant differences ($\alpha = 0.05$) between years, sites, or sampling dates, the Least Squares Means procedure was used to conduct multiple comparisons between years, sites and/or sampling dates (SAS, PROC GLM).

Covariates are being used to help explain differences in streptomycete levels and/or morphotype numbers among years, plantations, and sampling dates. Most of the covariates tested to date are weather-related variables, due both to their effectiveness and to their presumed independence of ELF field influence. So far, soil temperature (5 cm) and precipitation-related covariates have behaved in a fashion

indicative of ELF-independence ("Trees" Annual Report 1989, Element 1. Development, Installation and Operation of the Ambient Monitoring System, pages 10-62). Wherever covariance analysis detected significant differences, the results of pairwise comparisons (SAS, PROC GLM, Least Squares Means option) are presented. The capability of our experimental design to detect changes in mean values for either streptomycete levels or morphotype numbers is approximated, by using the 95 percent confidence interval for each sample mean (least squares means and standard errors, in the case of covariance analysis) to calculate the minimum detectable change (expressed as a percentage of each sample mean).

Description of Progress

Data for 1989 streptomycete levels and morphotype numbers associated with washed type 3 mycorrhizal fine roots are presented in Tables 139 and 140 as 1) the mean, and 2) the standard error of the sample mean for up to six samples per plantation. The larger S.E. for the 1989 levels and types compared to some of the previous years can be related to often having data from less than six samples per plantation and date. This was due both to problems with the June and July samples (less than six samples provided per site or insufficient sample mass provided for replicate analyses) and with bacterial or fungal contamination of several of the samples.

The relevant ANOVA statistics for the 1989 levels and morphotype numbers are presented in Tables 141 and 142, respectively. Means, standard errors, detectable differences and the results of least squares means comparisons are presented in Tables 143 and 144, for levels and morphotype numbers, respectively. There were no significant differences during 1989 in streptomycete levels ($p = 0.4052$) between sites. Morphotype numbers at the antenna site were not significantly different from those at the control site ($p = 0.5722$), but morphotype numbers at the ground site were significantly lower than those at the antenna ($p = 0.0111$) and control ($p = 0.0025$) sites. There was a significant seasonal effect on both levels ($p = 0.0004$) and morphotype numbers ($p = 0.0008$). The October levels were significantly lower than those of any other month but August; the May and September levels were higher than those of August (as well as October). Estimated detectable differences (using ANOVA) for streptomycete levels, among sites and sampling dates were approximately 1 to 2 percent of the mean. Morphotype numbers changed little through August. September morphotype numbers were significantly lower than those for May, and October numbers were significantly lower than those for May through August. The relatively large detectable difference estimates for morphotype numbers (approximately 10 to 20 percent for sites and 15 to 26 percent for months) indicates that these data are much less precise than are levels data. However, in light of the low average number of morphotypes encountered per sample (2.8 - 4.5; Table 140), loss of a single morphotype would probably still be detectable.

Table 139. Levels of streptomycetes (x 10^5) isolated from washed type 3 red pine mycorrhizal fine roots at each of the three ELF study plantations during 1989.

	Sampling Site					
	Control		Antenna		Ground	
Sampling Date	Mean[a]	S.E.[b]	Mean	S.E.	Mean	S.E.
26 May 1989	3.1	0.37	5.4	0.48	2.3[c]	
29 June 1989	2.6[d]	0.84	2.7[e]	0.22	3.4[e]	0.38
22 July 1989	3.1[d]	0.60	1.6[f]		3.6[f]	
14 Aug. 1989	2.1	0.30	2.1[d]	0.82	2.3[e]	0.46
12 Sept. 1989	3.0[e]	0.50	2.3	0.40	2.5[e]	0.46
26 Oct. 1989	1.4	0.13	1.9	0.34	1.7[f]	

a/ mean value (per gram soil, o.d.w.) for six root samples per plot, each sample representing the composited roots of 2-3 red pine seedlings
b/ standard error of the mean
c/ data from one sample
d/ data from three sample
e/ data from five samples
f/ data from two samples(no S.E. reported)

Table 140. Numbers of streptomycete morphotypes isolated from washed type 3 red pine mycorrhizal fine roots at each of the three ELF study plantations during 1989.

Sampling Date	Control		Antenna		Ground	
	Mean[a]	S.E.[b]	Mean	S.E.	Mean	S.E.
26 May 1989	4.3	0.56	4.7	0.56	3.0[c]	
29 June 1989	3.3[d]	0.33	4.0[e]	0.63	2.9[e]	0.29
22 July 1989	4.0[d]	0.58	4.0[f]		3.0[f]	
14 Aug. 1989	4.5	0.56	3.3[e]	0.33	2.9[d]	0.45
12 Sept. 1989	3.0[e]	0.49	3.3	0.42	2.4[d]	0.25
26 Oct. 1989	2.8	0.54	2.8	0.88	2.0[f]	

a/ mean value for six root samples per plot, each sample representing the composited roots of 2-3 red pine seedlings
b/ standard error of the mean
c/ data from one sample
d/ data from five samples
e/ data from three samples
f/ data from two samples (no S.E. reported)

Table 141. **ANOVA** table for detection of differences in **1989 levels** of streptomycetes associated with type 3 red pine mycorrhizae ($\log_{10}$-transformed data), among the three plantation subunits, by month (**May - October**), and without the use of covariates.

Source of Variation	df	SS	Type III SS	F	Signif. of F	r^2
Model	7	0.70		3.99	0.0010	0.29
Month	5		0.65	5.18	0.0004	
Plantation	2		0.05	1.01	0.4052	
Error	69	1.73				
Corrected Total	76	2.43				

Table 142. **ANOVA** table for detection of differences in numbers of streptomycete **types** associated in **1989** with type 3 red pine mycorrhizae ($\log_{10}$-transformed data), among the three plantation subunits, by month (**May - October**), and without the use of covariates.

Source of Variation	df	SS	Type III SS	F	Signif. of F	r^2
Model	7	0.87		4.88	0.0002	0.33
Month	5		0.62	4.83	0.0008	
Plantation	2		0.27	5.33	0.0071	
Error	69	1.76				
Corrected Total	76	2.64				

Table 143. Means, standard errors, detectable differences, and significantly different pairs of means, based on the levels model analyzed in Table 141.

Source of Variation	Mean[a]	Standard Error[b]	Detectable Difference[c]	Significant Difference[d]					
Month					1	2	3	4	5
May	5.45	0.045	1.62	May					
June	5.41	0.044	1.59	June					
July	5.43	0.060	2.17	July					
August	5.30	0.043	1.59	Aug	*				
September	5.43	0.039	1.41	Sept				*	
October	5.20	0.043	1.62	Oct	*	*	*		*
Plantation							G		A
Ground	5.40	0.037	1.34	Ground					
Antenna	5.34	0.031	1.14	Antenna					
Control	5.37	0.029	1.06	Control					

a/ mean of transformed data

b/ standard error of the least squares mean, provided by the Least Squares Means option of SAS Proc GLM

c/ estimated shift in the sample mean which would be detected 95 percent of the time ($\alpha = 0.05$), calculated as ($t_{.05,n-1}$ * S.E. / Mean), and expressed as a percentage of the sample mean

d/ $\alpha = 0.05$, Least squares Means Procedures

Table 144. Means, standard errors, detectable differences, and significantly different pairs of means, based on the types model analyzed in Table 142.

Source of Variation	Mean[a]	Standard Error[b]	Detectable Difference[c]	Significant Differences[d]					
Month					1	2	3	4	5
May	0.60	0.046	15.03	May					
June	0.53	0.045	16.64	June					
July	0.55	0.061	21.74	July					
August	0.55	0.043	15.32	Aug					
September	0.48	0.040	16.33	Sept	*				
October	0.33	0.044	26.13	Oct	*	*	*	*	*
Plantation					G	C			
Ground	0.41	0.037	17.69	Ground					
Antenna	0.54	0.031	11.25	Antenna	*				
Control	0.56	0.030	10.50	Control	*				

a/ mean of transformed data
b/ standard error of the least squares mean, provided by the Least Squares Means option of SAS Proc GLM
c/ estimated shift in the sample mean which would be detected 95 percent of the time (α = 0.05), calculated as ($t_{.05,n-1}$ * S.E. / Mean), and expressed as a percentage of the sample mean
d/ α = 0.05, Least Squares Means Procedure

The seasonal patterns for levels and morphotype numbers at the ground, antenna, and control site plantations are presented in Figures 88 - 90, as $\log_{10}$-transformed data for 1985 - 1989. The seasonal patterns of levels at the three plantations in 1989 again show similar trends, dropping off significantly in October. Morphotype numbers for all years but 1985 also typically show a significant decrease in October. The observed differences in monthly patterns, before ANACOV, between 1985-86 and 1987-89, may be related to the growth and maturation of the red pine seedlings during this same time period. The possibility of such relationships is being investigated.

Results of three-way ANOVA models for comparisons of streptomycete levels and morphotype numbers among years, sampling dates and plantations are presented in Tables 145 and 146, respectively. As in past years' analyses, significant differences were found among years and months with both data sets, but not among plantations. Results of Least Squares Means comparison tests are presented in Tables 147 and 148, for levels and morphotype numbers, respectively. Streptomycete levels for 1985, 1986, and 1989 were not significantly different from each other, but were significantly lower than the 1987 and 1988 levels, which also were similar. As in past years' analyses, the only month with significantly different levels was October. The numbers of observed morphotypes declined from 1985 to 1986 and from 1986 to 1987. No further decline, from 1987-1989, is apparent. This initial decline and then stabilization could represent establishment and persistence of those streptomycete types most capable of growth and survival with the red pine mycorrhizae at these sites. Morphotype numbers recovered in October were significantly lower than those found from May to September, and May numbers were significantly higher than those found from July to October. The detectable difference levels for this $\log_{10}$-transformed 5-year data set as a whole were less than 1 percent for streptomycete levels and between 5 and 9 percent for morphotype numbers.

Correlation analyses were conducted as the first step in exploring relationships of seasonal patterns of streptomycete levels and morphotype numbers with weather, other environmental, and vegetation-associated variables. Over 30 variables related to temperature, precipitation, soil moisture, nutrient status, rhizosphere soil pH, previous forest cover, mycorrhizae levels, and seedling growth and vigor were analyzed in order to determine their potential value as covariates to explain differences among years and months detected by ANOVA. Some of the variables having p values less than 0.05 and correlation coefficients greater than $|0.3000|$ were selected for the initial analysis of covariance (ANACOV) studies. Priority has been given to weather-related variables, which are presumed to be independent of direct ELF field influence. Temperature- and precipitation-related variables were evaluated in two basic forms: 1) as the running totals leading up to each sampling date, and 2) as totals for the 30 day period previous to each sampling date.

The first round of covariates tested with 1985-1989 streptomycete levels and morphotype numbers included only

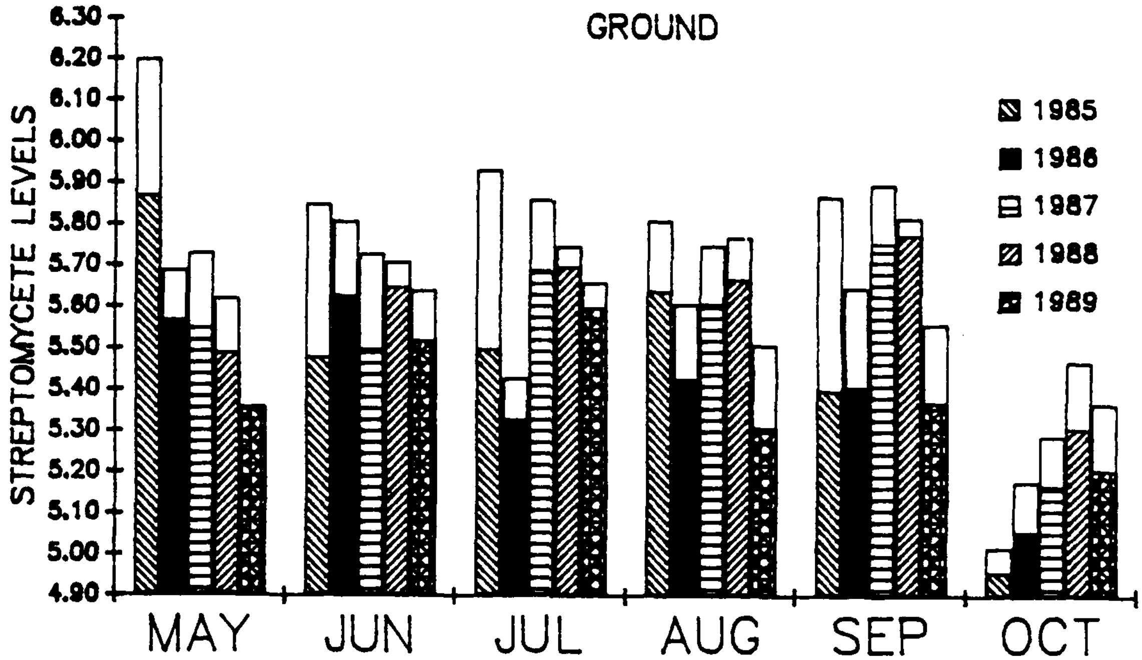
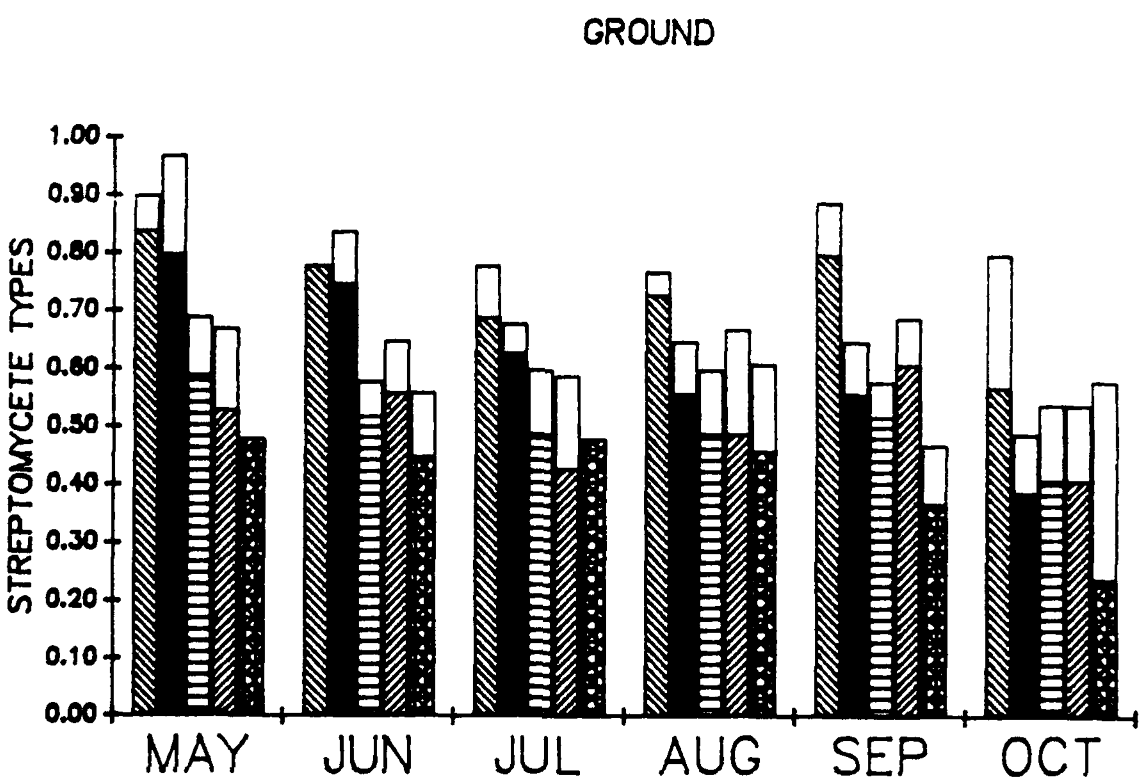


Figure 88. Seasonal patterns of streptomycete levels and morphotype numbers at the ground site plantation from 1985 through 1989. (mean ± s.e.)



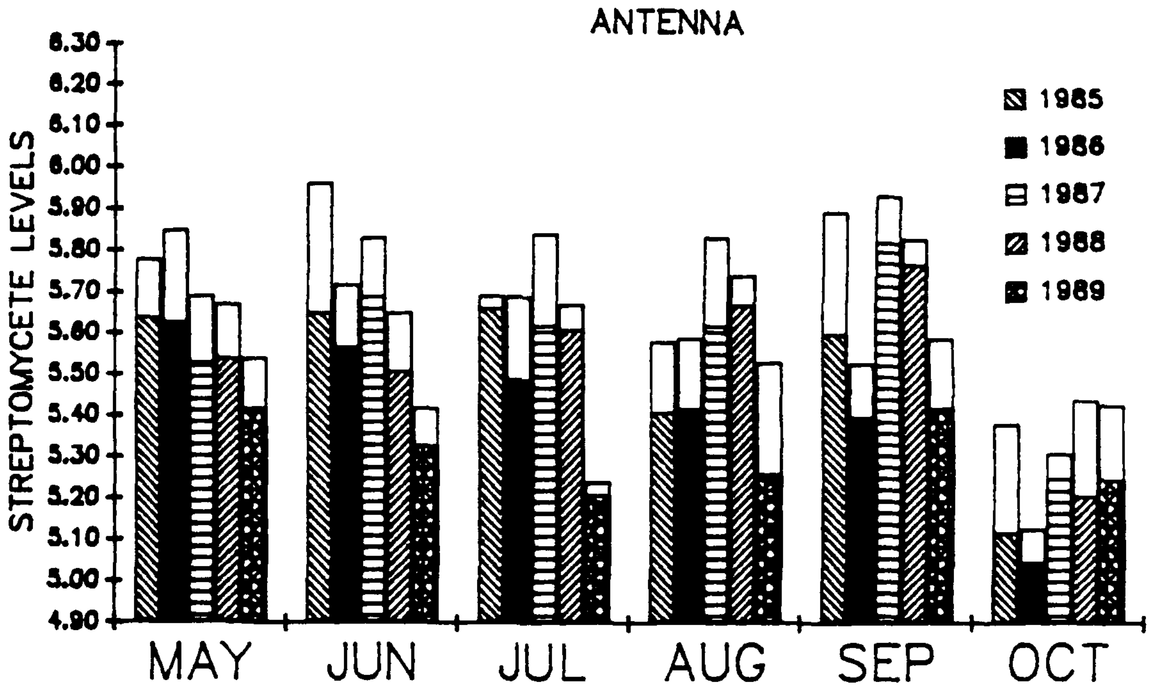
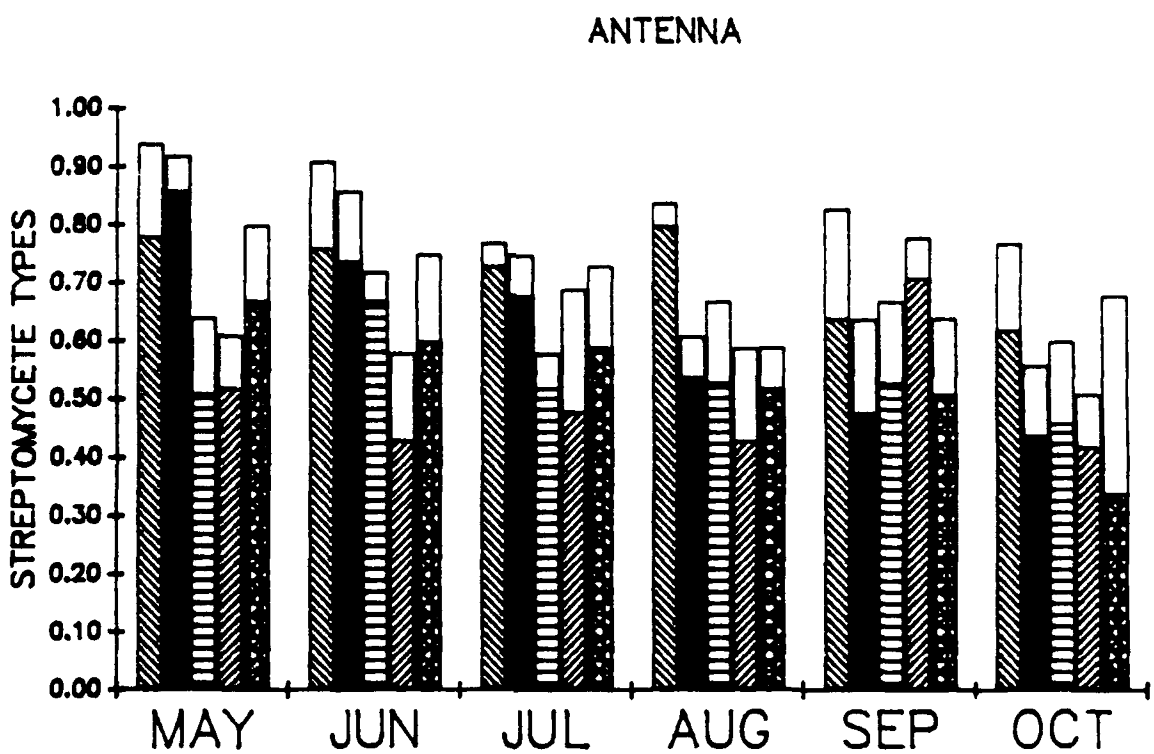


Figure 89. Seasonal patterns of streptomycete levels and morphotype numbers at the antenna site plantation from 1985 through 1989. (mean ± s.e.)



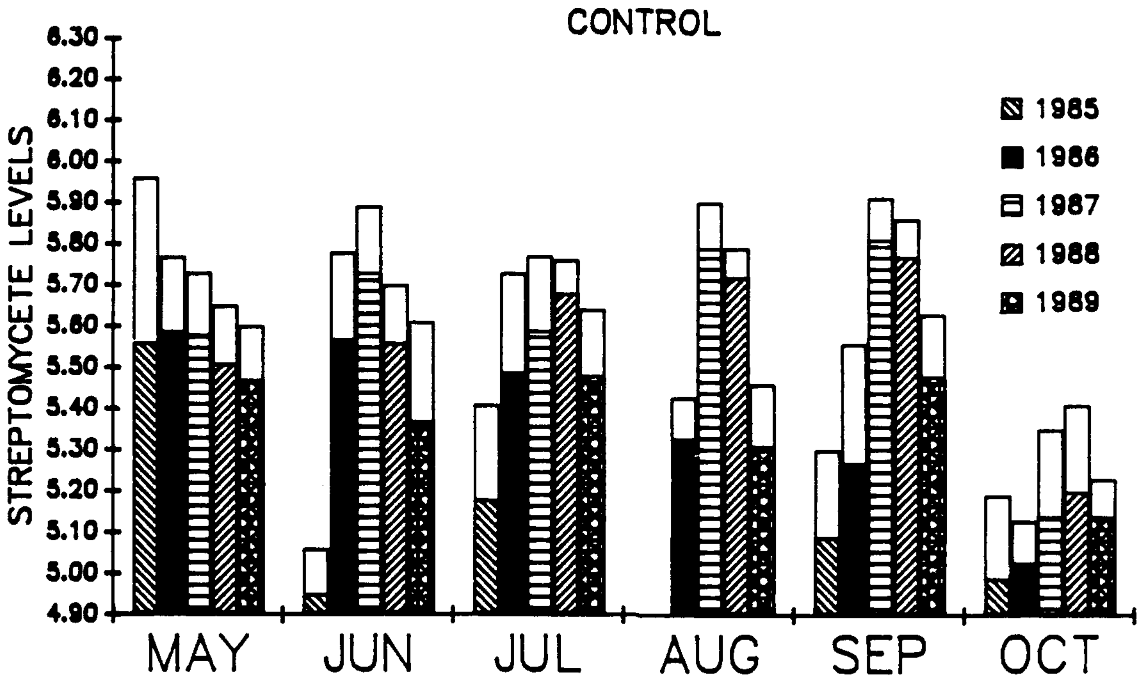


Figure 90. Seasonal patterns of streptomycete levels and morphotype numbers at the control site plantation from 1985 through 1989. (mean ± s.e.)

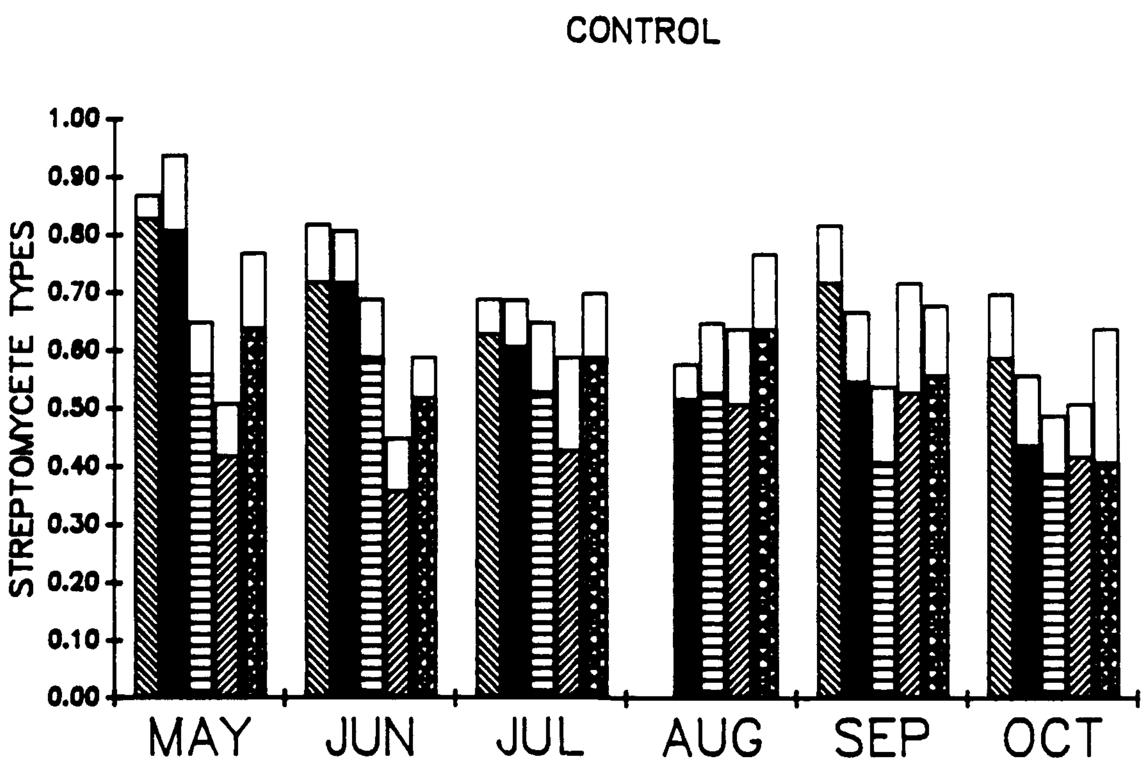


Table 145. **ANOVA** table for detection of differences in streptomycete **levels** associated with type 3 red pine mycorrhizae (log_{10}-transformed data), among the three plantation subunits, by year and month (**May - October**), and without the use of covariates.

Source of Variation	df	SS	Type III SS	F	Signif. of F	r^2
Model	11	14.20		33.65	0.0001	0.46
Year	4		3.97	25.89	0.0001	
Month	5		9.97	52.00	0.0001	
Plantation	2		0.10	1.36	0.2571	
Error	440	16.88				
Corrected Total	451	31.08				

Table 146. **ANOVA** table for detection of differences in numbers of streptomycete **types** associated with type 3 red pine mycorrhizae (log_{10}-transformed data), among the three plantation subunits, by year and month (**May - October**), and without the use of covariates.

Source of Variation	df	SS	Type III SS	F	Signif. of F	r^2
Model	11	3.84		10.19	0.0001	0.20
Year	4		2.35	17.12	0.0001	
Month	5		1.44	8.39	0.0001	
Plantation	2		0.05	0.66	0.5190	
Error	440	15.09				
Corrected Total	451	18.95				

Table 147. Means, standard errors, detectable differences, and significantly different pairs of means, based on the levels model analyzed in Table 145.

Source of Variation	Mean[a]	Standard Error[b]	Detectable Difference[c]	Significant Differences[d]					
Year					5	6	7	8	
1985	5.39	0.027	0.98	1985					
1986	5.40	0.019	0.69	1986					
1987	5.58	0.019	0.67	1987	*	*			
1988	5.57	0.019	0.67	1988	*	*			
1989	5.37	0.022	0.80	1989			*	*	
Month					1	2	3	4	5
May	5.53	0.023	0.82	May					
June	5.53	0.023	0.82	June					
July	5.52	0.024	0.85	July					
August	5.51	0.023	0.82	Aug					
September	5.56	0.022	0.78	Sept					
October	5.14	0.023	0.88	Oct	*	*	*	*	*
Plantation					G	A			
Ground	5.47	0.017	0.61	Ground					
Antenna	5.48	0.016	0.57	Antenna					
Control	5.44	0.016	0.58	Control					

a/ mean of transformed data
b/ standard error of the least squares mean, provided by the Least Squares Means option of SAS Proc GLM
c/ estimated shift in the sample mean which would be detected 95 percent of the time ($\alpha = 0.05$), calculated as ($t_{0.05,n-1}$ * S.E. / Mean), and expressed as a percentage of the sample mean
d/ $\alpha = 0.05$, Least Squares Means Procedure

Table 148. Means, standard errors, detectable differences, and significantly different pairs of means, based on the types model analyzed in Table 146.

Source of Variation	Mean[a]	Standard Error[b]	Detectable Difference[c]	Significant Differences[d]					
Year					5	6	7	8	
1985	0.72	0.026	7.08	1985					
1986	0.62	0.018	5.69	1986	*				
1987	0.51	0.018	6.92	1987	*	*			
1988	0.51	0.018	6.92	1988	*	*			
1989	0.51	0.021	8.07	1989	*	*			
Month					1	2	3	4	5
May	0.66	0.021	6.24	May					
June	0.61	0.021	6.75	June					
July	0.56	0.022	7.70	July	*				
August	0.56	0.022	7.70	Aug	*				
September	0.57	0.021	7.22	Sept	*				
October	0.48	0.021	8.58	Oct	*	*	*	*	*
Plantation							G		C
Ground	0.56	0.016	5.60	Ground					
Antenna	0.58	0.015	5.07	Antenna					
Control	0.58	0.015	5.07	Control					

a/ mean of transformed data
b/ standard error of the least squares mean, provided by the Least Squares Means option of SAS Proc GLM
c/ estimated shift in the sample mean which would be detected 95 percent of the time ($\alpha = 0.05$), calculated as ($t_{0.05,n-1}$ * S.E. / Mean), and expressed as a percentage of the sample mean
d/ $\alpha = 0.05$, Least Squares Means Procedure

weather-related variables. For streptomycete levels, ANACOV (Table 149) explained all differences between years ($p = 0.2506$) which had been detected by ANOVA (Tables 145 and 147), without inordinately raising detectable differences (Table 151). The corresponding F values for overall differences between plantations and monthly sampling dates were also reduced, providing better explanation of plantations. This first ANACOV indicates that, when the weather-related covariates are taken into account, mean streptomycete levels decline significantly as the sampling seasons progress.

For morphotype numbers, ANACOV (Table 150) explained a number of the differences between years which were detected by ANOVA (Tables 146 and 148), with only a modest increase in detectable differences to 9 - 12 percent (Table 152). However, since the number of morphotypes observed is quite small (Table 140), loss of a single morphotype would likely be detected. Mean numbers of morphotypes observed, adjusted for the covariates (Table 150), appear to be declining with plantation age (while total population levels remain stable). Differences between sampling dates were explained, but with greatly increased detectable differences. The covariate data utilized in the models represented by Tables 149 through 152 are presented in Tables 153 through 162.

Because of this success in explaining differences in streptomycete levels among years and plantations using weather-related covariates, we again do not find it necessary to analyze the streptomycete levels (or types) data without the October sampling date, as we did for the 1987 annual report.

Morphotype Distribution and Characterization

Streptomycete morphotypes characterized during the 1989 sampling season from type 3 washed mycorrhizal fine roots are presented in Table 163. In general, the same morphotypes and same incidence patterns were found during the 1989 sampling season as in 1986 through 1988. By using reactions on secondary media, type D was divided into two types, D (a very commonly occurring type in 1989 as in past seasons) and E (found less frequently until late in the sampling season). Morphotype B was again detected at each plantation on each sampling date; it was usually isolated from three to six samples/plantation per date, often as the predominate type. Morphotypes D, J, S, and T were also commonly detected, as in 1987 and in 1988. The most notable decrease in incidence was of morphotype F, which had a high frequency of isolation in previous seasons. Levels of morphotypes K and W also decreased, although the 1989 W levels were more similar to those found prior to 1988. Increased isolation of morphotypes N and R were also found.

Other similarities were present in common morphotype incidence among those plantation site samples consisting only of mycorrhizal type 3 fine roots, i.e., 1986 - 1989. For the control plantation, the incidence of B and S were about the same for all four years. Morphotypes D, J, R, T, and U levels were about equal for 1986, 1987, and 1989. Morphotypes B, D, J, K,

Table 149. **Covariance** analysis table far detection of differences in streptomycete **levels** associated with type 3 red pine mycorrhizae ($\log_{10}$-transformed data), among the three plantation subunits, by year and by month (**May - October**), using **ATDDRT**, **PRWRT**, and **PR.1RT** as covariates[a].

Source of Variation	df	SS	Type III SS	F	Signif. of F	r^2
Model	14	16.24		34.18	0.0001	0.52
Year	4		0.18	1.35	0.2506	
Month	5		4.85	28.56	0.0001	
Plantation	2		0.06	0.84	0.4344	
PR.1RT	1		0.72	21.09	0.0001	
PRWRT	1		0.91	26.56	0.0001	
ATDDRT	1		0.49	14.52	0.0002	
Error	437	14.84				
Corrected Total	451	31.08				

a/ ATDDRT is the running total number of air temperature degree days (4.4°C basis); PRWRT is the running total of rainfall for the year; PR.1RT is the running total of the number of days with precipitation events delivering at least 0.01 inch of rain.

Table 150. **Covariance** analysis table for detection of differences in numbers of streptomycete **types** associated with type 3 red pine mycorrhizae ($\log_{10}$-transformed data), among the three plantation subunits, by year and month (**May - October**), using **ST5DDRT**, **PRWRT**, and **PR.01RT** as covariates[a].

Source of Variation	df	SS	Type III SS	F	Signif. of F	r^2
Model	14	4.40		9.45	0.0001	0.23
Year	4		2.28	17.12	0.0001	
Month	5		0.27	1.60	0.1601	
Plantation	2		0.10	1.46	0.2332	
PRWRT	1		0.29	8.68	0.0034	
PR.01RT	1		0.31	9.36	0.0023	
ST5DDRT	1		0.12	3.50	0.0619	
Error	437	14.54				
Corrected Total	451	18.95				

a/ ST5DDRT is the running total of degree days for the year 5 cm below the soil surface (4.4°C basis); PRWRT is the running total of rainfall for the year; PR.01RT is the running total of the number of days with precipitation events delivering at least 0.01 inch of rain.

Table 151. Adjusted means, standard errors, detectable differences, and significantly different pairs of means, based on the levels model analyzed in Table 149.

Source of Variation	Adjusted Mean[a]	Standard Error[b]	Detectable Difference[c]	Significant Differences[d]					
Year					5	6	7	8	
1985	5.46	0.043	1.54	1985					
1986	5.46	0.026	0.93	1986					
1987	5.58	0.027	0.95	1987					
1988	5.49	0.023	0.82	1988					
1989	5.44	0.025	0.90	1989					
Month					1	2	3	4	5
May	5.99	0.052	1.70	May					
June	5.82	0.097	3.27	June	*				
July	5.62	0.038	1.33	July	*	*			
August	5.37	0.045	1.64	Aug	*	*	*		
September	5.28	0.096	3.56	Sept	*	*	*		
October	4.80	0.130	5.31	Oct	*	*	*	*	*
Plantation						G		A	
Ground	5.50	0.021	0.75	Ground					
Antenna	5.48	0.017	0.61	Antenna					
Control	5.45	0.020	0.72	Control					

a/ adjusted mean of transformed data

b/ standard error of the least squares mean, provided by the Least Squares Means option of SAS Proc GLM

c/ estimated shift in the sample mean which would be detected 95 percent of the time ($\alpha = 0.05$), calculated as ($t_{0.05,n-1}$ * S.E. / Mean), and expressed as a percentage of the sample mean

d/ $\alpha = 0.05$, Least Squares Means procedure

Table 152. Adjusted means, standard errors, detectable differences, and significantly different pairs of means, based on the types model analyzed in Table 150.

Source of Variation	Adjusted Mean[a]	Standard Error[b]	Detectable Difference[c]	Significant Differences[d]				
Year					5	6	7	8
1985	0.75	0.043	11.24	1985				
1986	0.58	0.031	10.48	1986	*			
1987	0.55	0.035	12.47	1987	*			
1988	0.45	0.026	11.32	1988	*	*	*	
1989	0.56	0.026	9.10	1989	*			*
Month					1 2 3 4 5			
May	0.76	0.141	36.36	May				
June	0.69	0.091	25.85	June				
July	0.58	0.037	12.50	July				
August	0.51	0.040	15.37	Aug				
September	0.50	0.092	36.06	Sept				
October	0.44	0.133	59.25	Oct				
Plantation							G	C
Ground	0.56	0.017	5.95	Ground				
Antenna	0.57	0.015	5.16	Antenna				
Control	0.60	0.016	5.23	Control				

a/ adjusted mean of transformed data

b/ standard error of the least squares mean, provided by the Least Squares Means option of SAS Proc GLM

c/ estimated shift in the sample mean which would be detected 95 percent of the time (α = 0.05), calculated as ($t_{0.05,n-1}$ * S.E. / Mean), and expressed as a percentage of the sample mean

d/ α = 0.05, Least Squares Means procedure

Table 153. Values of ATDDRT, the running total of air temperature degree days (4.4°C basis), and ST5DDRT, the running total of soil temperature degree days (5 cm depth, 4.4°C basis), achieved by each sampling date in 1985.

	Sampling Date					
Site[a]	21 May	17 Jun	16 Jul	21 Aug	25 Sep	23 Oct
ATDDRT						
111	236	430	768	1199	1529	1580
112	237	431	768	1197	1526	1581
113	237	432	766	1195	1526	1584
211	237	429	778	1191	1504	1607
212	235	432	762	1167	1548	1564
213	236	426	745	1215	1526	1585
311	282	486	858	1303	1619	1678
312	283	502	849	1285	1647	1691
313	278	492	842	1293	1631	1712
ST5DDRT						
111	225	495	867	1331	1691	1816
112	224	495	895	1349	1717	1800
113	233	519	872	1347	1707	1772
211	266	519	871	1417	1843	1802
212	228	496	915	1464	1717	1932
213	239	561	959	1347	1801	1894
311	213	465	869	1370	1665	1746
312	212	473	839	1300	1750	1791
313	215	470	831	1314	1689	1838

a/ First two digits represent plantation (11 = ground; 21 = antenna; 31 = control); third digit represents plot replicate in each plantation.

Table 154. Values of PRWRT, the running total of precipitation, PR.01RT, the running total of days with precipitation events totaling at least 0.01 inch, and PR.10RT, the running total of days with precipitation events totaling at least 0.10 inch, achieved by each sampling date in 1985.

	Sampling Date					
Site[a]	21 May	17 Jun	16 Jul	21 Aug	25 Sep	23 Oct
PRWRT						
11	6.1	8.8	11.5	16.2	21.4	26.5
21	6.0	8.9	11.7	16.5	21.9	27.0
31	4.0	7.3	8.2	10.6	16.5	21.4
PR.01RT						
11	23	34	43	54	71	86
21	21	32	43	54	70	87
31	21	33	44	59	74	88
PR.1RT						
11	11	16	22	33	43	50
21	11	18	23	33	44	51
31	11	19	23	30	38	45

a/ First two digits represent plantation (11 = ground; 21 = antenna; 31 = control); third digit represents plot replicate in each plantation.

Table 155. Values of ATDDRT, the running total of air temperature degree days (4.4°C basis), and ST5DDRT, the running total of soil temperature degree days (5 cm depth, 4.4°C basis), achieved by each sampling date in 1986.

	Sampling Date					
Site[a]	29 May	23 Jun	21 Jul	18 Aug	23 Sep	22 Oct
ATDDRT						
111	299	545	921	1286	1539	1661
112	314	561	943	1328	1600	1721
113	293	531	894	1260	1514	1627
211	306	563	941	1316	1576	1695
212	309	569	951	1326	1586	1706
213	315	579	965	1343	1602	1723
311	332	605	988	1369	1661	1820
312	338	617	1011	1391	1682	1846
313	333	602	985	1362	1652	1809
ST5DDRT						
111	322	625	1044	1441	1763	1909
112	314	599	996	1391	1716	1869
113	311	603	1007	1401	1732	1889
211	328	626	1045	1453	1784	1930
212	291	567	959	1344	1653	1791
213	391	701	1127	1557	1917	2080
311	308	599	1008	1425	1763	1910
312	320	627	1045	1468	1810	1971
313	273	544	930	1335	1664	1816

a/ First two digits represent plantation (11 = ground; 21 = antenna; 31 = control); third digit represents plot replicate in each plantation.

Table 156. Values of PRWRT, the running total of precipitation, PR.01RT, the running total of days with precipitation events totaling at least 0.01 inch, and PR.10RT, the running total of days with precipitation events totaling at least 0.10 inch, achieved by each sampling date in 1986.

	Sampling Date					
Site[a]	29 May	23 Jun	21 Jul	18 Aug	23 Sep	22 Oct
PRWRT						
11	1.2	2.1	3.3	5.9	8.9	13.0
21	0.5	1.4	2.5	5.1	8.2	12.2
31	0.9	1.7	4.4	6.8	9.2	13.3
PR.01RT						
11	6	11	19	33	51	64
21	6	11	19	33	51	64
31	7	13	24	34	48	60
PR.1RT						
11	2	5	8	16	25	32
21	1	4	7	15	24	31
31	3	6	15	21	30	39

a/ First two digits represent plantation (11 = ground; 21 = antenna; 31 = control); third digit represents plot replicate in each plantation.

Table 157. Values of ATDDRT, the running total of air temperature degree days (4.4°C basis), and ST5DDRT, the running total of soil temperature degree days (5 cm depth, 4.4°C basis), achieved by each sampling date in 1987.

	Sampling Date					
Site[a]	29 May	23 Jun	21 Jul	17 Aug	14 Sep	12 Oct
ATDDRT						
111	278	619	994	1401	1661	1801
112	294	640	1018	1427	1688	1828
113	278	622	998	1406	1667	1806
211	307	652	1029	1439	1705	1847
212	298	646	1026	1442	1717	1865
213	305	657	1040	1458	1732	1880
311	371	733	1123	1541	1817	1971
312	367	750	1166	1614	1921	2099
313	344	700	1084	1494	1772	1926
ST5DDRT						
111	315	649	1023	1417	1725	1915
112	296	635	1007	1399	1694	1871
113	343	703	1098	1510	1820	2001
211	302	634	1016	1416	1720	1902
212	287	623	1014	1425	1737	1926
213	368	731	1131	1555	1886	2088
311	299	646	1043	1469	1801	2001
312	268	590	965	1378	1701	1904
313	331	680	1080	1510	1832	2021

a/ First two digits represent plantation (11 = ground; 21 = antenna; 31 = control); third digit represents plot replicate in each plantation.

Table 158. Values of PRWRT, the running total of precipitation, PR.01RT, the running total of days with precipitation events totaling at least 0.01 inch, and PR.10RT, the running total of days with precipitation events totaling at least 0.10 inch, achieved by each sampling date in 1987.

	Sampling Date					
Site[a]	29 May	23 Jun	21 Jul	17 Aug	14 Sep	12 Oct
PRWRT						
11	3.6	6.3	12.6	14.9	15.6	18.3
21	3.7	6.4	12.7	15.1	16.2	19.1
31	3.3	5.3	10.1	14.7	15.6	17.8
PR.01RT						
11	19	32	48	56	64	76
21	20	33	49	59	70	81
31	23	35	48	58	69	82
PR.1RT						
11	10	15	25	28	30	38
21	10	15	25	28	31	38
31	9	14	25	32	37	42

a/ First two digits represent plantation (11 = ground; 21 = antenna; 31 = control); third digit represents plot replicate in each plantation.

Table 159. Values of ATDDRT, the running total of air temperature degree days (4.4°C basis), and ST5DDRT, the running total of soil temperature degree days (5 cm depth, 4.4°C basis), achieved by each sampling date in 1988.

	Sampling Date					
Site[a]	27 May	21 Jun	19 Jul	16 Aug	13 Sep	11 Oct
ATDDRT						
111	209	566	956	1409	1637	1794
112	214	571	962	1419	1700	1865
113	212	564	932	1382	1636	1797
211	228	596	1012	1481	1770	1927
212	234	605	1018	1487	1776	1934
213	244	619	1031	1499	1788	1946
311	278	661	1078	1551	1846	2011
312	295	696	1145	1659	2008	2233
313	[illegible]	653	1077	1545	1847	2024
ST5DDRT						
111	167	462	860	1307	1637	1841
112	214	551	950	1392	1713	1915
113	227	571	982	1435	1766	1975
211	190	501	898	1341	1662	1857
212	252	612	1052	1531	1867	2065
213	233	574	993	1456	1794	2001
311	224	586	1008	1464	1797	2003
312	216	568	986	1448	1794	2013
313	239	605	1030	1491	1846	2073

a/ First two digits represent plantation (11 = ground; 21 = antenna; 31 = control); third digit represents plot replicate in each plantation.

Table 160. Values of PRWRT, the running total of precipitation, PR.01RT, the running total of days with precipitation events totaling at least 0.01 inch, and PR.10RT, the running total of days with precipitation events totaling at least 0.10 inch, achieved by each sampling date in 1988.

	Sampling Date					
Site[a]	27 May	21 Jun	19 Jul	16 Aug	13 Sep	11 Oct
PRWRT						
11	1.1	1.9	5.3	9.9	14.0	17.2
21	1.2	2.0	5.1	9.7	13.6	16.8
31	1.3	2.2	5.5	9.2	12.4	14.2
PR.01RT						
11	11	18	28	38	48	64
21	10	15	24	33	43	58
31	10	16	24	39	50	61
PR.1RT						
11	4	7	11	18	25	33
21	4	7	11	19	27	35
31	4	7	11	18	23	30

a/ First two digits represent plantation (11 = ground; 21 = antenna; 31 = control); third digit represents plot replicate in each plantation.

Table 161. Values of ATDDRT, the running total of air temperature degree days (4.4°C basis), and ST5DDRT, the running total of soil temperature degree days (5 cm depth, 4.4°C basis), achieved by each sampling date in 1989.

Site[a]	Sampling Date 26 May	29 Jun	22 Jul	14 Aug	12 Sep	26 Oct
ATDDRT						
111	186	504	832	1167	1487	1680
112	189	512	842	1181	1505	1697
113	187	502	824	1156	1474	1663
211	194	527	874	1221	1546	1752
212	195	522	863	1204	1529	1728
213	199	528	869	1211	1538	1738
311	231	622	986	1356	1721	1959
312	246	674	1054	1440	1831	2087
313	214	569	918	1271	1610	1831
ST5DDRT						
111	150	488	806	1145	1483	1689
112	177	520	832	1155	1487	1691
113	165	518	859	1211	1575	1812
211	169	507	825	1159	1504	1718
212	176	538	878	1225	1572	1775
213	216	617	992	1369	1740	1941
311	171	545	903	1276	1653	1872
312	174	548	894	1264	1644	1885
313	226	635	996	1379	1775	2024

a/ First two digits represent plantation (11 = ground; 21 = antenna; 31 = control); third digit represents plot replicate in each plantation.

Table 162. Values of PRWRT, the running total of precipitation, PR.01RT, the running total of days with precipitation events totaling at least 0.01 inch, and PR.10RT, the running total of days with precipitation events totaling at least 0.10 inch, achieved by each sampling date in 1989.

	Sampling Date					
Site[a]	26 May	29 Jun	22 Jul	14 Aug	12 Sep	26 Oct
PRWRT						
11	1.2	6.1	6.6	9.1	12.2	14.7
21	1.2	6.3	6.8	8.8	11.9	14.1
31	2.1	5.6	5.8	6.8	8.2	9.5
PR.01RT						
11	12	29	33	42	51	68
21	12	29	33	42	52	68
31	18	33	35	43	52	64
PR.1RT						
11	5	14	17	22	27	32
21	5	14	17	23	28	33
31	6	15	16	20	24	28

a/ First two digits represent plantation (11 = ground; 21 = antenna; 31 = control); third digit represents plot replicate in each plantation.

Table 163. Streptomycete morphotypes associated with washed mycorrhizal type 3 fine roots.

Sampling Date (1989)	Study Site[a]	Streptomycete Morphotype																			
		A	B	C	D	E	F	G	H	J	K	N	O	P	Q	R	S	T	U	V	W
26 May	C	X	X[c]		X[b]		X[b]			X		X[b]			X	X[b]		X[b]	X		
	A		X[c]	X	X[b]	X	X		X[b]	X[b]	X[b]	X	X		X	X[b]	X[b]	X[b]	X[b]		
	G[d]	X								X					X						
29 June	C		X[b]		X	X			X					X		X		X			
	A		X[c]		X[c]	X	X		X[b]				X		X[b]	X	X	X[b]	X		
	G		X[b]		X					X[b]					X	X	X				
22 July	C		X[c]		X			X		X						X[b]	X[b]	X			
	A[e]		X[b]				X		X		X[b]	X					X				
	G[e]		X[b]		X																
14 August	C	X[c]	X	X[b]	X[b]	X[b]	X	X[b]	X[b]	X	X	X	X	X	X[b]	X[b]	X[b]				
	A	X[b]	X	X[b]		X		X	X	X		X			X		X				
	G	X	X[c]	X	X[b]	X		X								X					
12 September	C	X[c]		X[b]		X[b]				X							X	X	X[c]		
	A		X[c]	X	X[b]	X[b]			X	X	X	X			X		X[b]		X[b]		
	G		X[b]		X[b]	X[b]				X		X				X	X		X[b]		
26 October	C		X[c]		X[b]	X[b]				X[b]	X[b]	X				X	X		X		
	A		X[c]		X[b]	X			X	X	X[b]	X				X	X	X	X		X
	G[e]		X[c]							X		X									

[a] C - Control Plantation; A - Antenna Plantation; G - Ground Plantation
[b] detected in two or more of replicate samples/plantation
[c] predominant type in two or more of replicate samples/plantation
d only one sample with data
e only two samples with data

and U were commonly found with the antenna plantation samples from 1986 - 1989. Morphotype N incidence was the same in 1989 as in 1988. The levels of morphotype S were similar to those reported in 1986 and 1987. A previously infrequently detected morphotype, H, was found only with the antenna plantation samples during 1989, detected in five of the six months' samples. There were relatively few ground plantation sample morphotype data for the 1989 season, due to sample preparation and bacterial contamination problems. As in past years with this site, morphotypes B and J were commonly detected. The incidences of morphotypes A and D were similar to those found in 1986 and 1988, while the incidence of morphoptype U was similar to the levels in 1986 and 1987.

From two to six streptomycete isolates representing each of the morphotypes detected form May through October during 1989 (Table 163) were tested for ability to degrade calcium oxalate, cellulose, and lignocellulose. Of the 109 isolates tested, 69%, 70%, and 72% degraded calcium oxalate, cellulose, and lignocellulose, respectively. Approximately 60% of all isolates representing over 50% of the morphotypes could degrade all three substrates. These results are similar to those found with streptomycete isolates form the 1987 and 1988 sampling seasons, indicating little change in either morphotypes or their activities in the past three sampling seasons.

Projected Work

Analyses in 1990 will deal with determination of streptomycete levels and morphotype numbers associated with washed red pine type 3 mycorrhizal fine roots. There will be no change in sampling or detection methods or in numbers of samples analyzed per plantation. The difficulties encountered with root sample preparation during the 1989 season should not be repeated. However, we do not have direct control over preparation of these samples. We have communicated the need for prompt preparation and delivery to the responsible "TREES" staff; we also recognize that careful preparation of these samples is a time-consuming task. The time interval between root collection and delivery of roots for streptomycete analyses will be kept as short as feasible, and always no more than 9 days.

Emphasis will continue to be placed on covariate analysis of the data in modeling environmental/biological variables affecting streptomycete population differences between plantation subunits, sampling dates, and years. Year by site interactions will be examined. Covariates such as actual evapotranspiration (AET) will be examined; elapsed time (in days) between root samples collection and streptomycete analysis will also be included as a covariate to assess the impact of this parameter.

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GLOSSARY

Actinomycete	A large group of true bacteria, characterized by a mycelial vegetative structure.
Basal Area	The area of the cross section of a tree at DBH.
Biomass	The amount of living matter in a unit area.
DBH	Diameter at breast height. Average stem diameter, outside bark, measured 4.5 feet above the ground.
Ectomycorrhizae	The type of mycorrhizae in which the fungus component grows only intercellularly within its host root, and produces an external mantle.
Habitat Type	Land areas potentially capable of producing similar plant communities at maturity.
Litter	Dead, largely unincorporated leaves and other plant parts on the forest floor.
Mycorrhizae	A mutually beneficial association between plant roots and certain highly specialized parasitic fungi.
Mycorrhizoplane	The rhizoplane of mycorrhizae.
Mycorrhizosphere	The rhizosphere of mycorrhizae.
NESS	National Earth Satellite Service.
NOAA	National Oceanographic and Atmospheric Administration.

Nutrient Flux	In litter decomposition, the balance between the rates of nutrient movement into and out of decomposing litter.
Rhizoplane	The actual surface of plant roots, together with any closely adhering particles of soil or debris.
Rhizosphere	The narrow zone of soil subject to the influence of living roots.
Streptomycete	Members of the genus *Streptomyces*, a group of actinomycetes which reproduce by forming spores.